MEMOIRS

OF

GEOLOGICAL SURVEY OF INDIA.

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VOLUME 71.

THE GEOLOGY OF GANGPUR STATE, EASTERN STATES. BY M. S. KRISHNAN, M.A., PH. D. (LOND.), A.R.C.S., D.I.C., *Geologist, Geological Survey of India.* (With Plates 1 TO 19.)

Published by order of the Government of India.

CALCUTTA: SOLD AT THE CENTRAL BOOK DEPÔT, 8, HASTINGS STREET, AND AT THE OFFICE OF THE GEOLOGICAL SURVEY OF INDIA, 27, CHOWRINGHEE ROAD.

DELHI: SOLD AT THE OFFICE OF THE MANAGER OF PUBLICATIONS.

1937.

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THE GEOLOGY OF GANGPUR STATE, EASTERN STATES. BY M. S. KRISHNAN, M.A., PH.D. (LOND.), A.R.C.S., D.I.C., *Geologist, Geological Survey of India.* (With Plates 1 to 19.)

PART I.—GENERAL GEOLOGY.

CHAPTER I.—PHYSICAL FEATURES.

INTRODUCTION.

Area surveyed.

The area dealt with in this paper comprises the southern half of the sheet No. 73B of the Survey of India, lying between the north latitudes 22° 0′ and 22° 30′ and the east longitudes 84° 0′ and 85° 0′. For the sake of completeness its extensions to the east and west have also been included. By far the greater part of the area is occupied by the Gangpur State, the borders comprising portions of the British districts of Ranchi, Singhbhum and Sambalpur and the Feudatory States of Bonai, Bamra and Jashpur. On the west, the limit of the mapped area has been determined by the political boundary of Bihar and Orissa and the geological boundary of the crystalline schists, while on the east the limit of the structural unit has been taken into account.

Purpose of the survey.

A programme of resurvey of Chota Nagpur and Orissa was taken up some 15 years ago, and work was commenced in the Singhbhum district particularly in connection with the iron-ore deposits. Two memoirs, one describing North Singhbhum and the other South Singhbhum, have already

appeared. Special interest was felt in the present area when Dr. E Spencer of Messrs. Bird & Co. of Calcutta discovered, in the course of a survey for economic purposes, that there was here a dome shaped structure exposing manganiferous rocks of the gondite type and crystalline marbles. It was thought that the mapping of the region would serve to throw light on the relationship between the rocks of the Nagpur area in the Central Provinces and those of the Singhbhum area in Bihar and Orissa.

Maps.

The mapping of the whole area was done independently by the present writer between the seasons 1927-28 and 1932-33. Only for the portions covered by the districts of Ranchi and Singhbhum are the modern topographical maps of the Survey of India, on the scale of one inch to a mile, available. The rest of the area was mapped on modern sheets on the scale of half-inch to a mile.

Acknowledgments.

During the course of fieldwork the writer has received sympathetic help from many sources which it is a pleasure to acknowledge. He is indebted to the administrative officers of the different districts and States covered in the area, *viz.*, Gangpur, Bonai, Bamra, Ranchi and Singhbhum and particularly to those of Gangpur State. To Mr. H. D. Christian, formerly Dewan and now Superintendent of Gangpur State, and to Mr. S. N. Khanna, Forest Officer of the same State, he is greatly obliged for their constant help and hospitality on many occasions and for smoothening the difficulties of long tours in out-of-the-way places. To the officers of various mining companies in the area—the Bisra Stone Lime Co., (particularly to Messrs. R. F. Alexander and F. H. Legg), the Tata Iron and Steel Co. and Messrs. B. P. Byramjee & Co., he is thankful for their courtesy and for information supplied during visits to their quarries.

He has also benefited considerably by discussions with several of his colleagues. In particular, the valuable suggestions and advice of Sir Lewis Fermor, Dr. C. S. Fox and Mr. D. N. Wadia have been freely drawn upon in bringing the report to its present form. The author's thanks are also due to Mr. P. C. Roy, Curator of the Geological Survey and Museum, for several of the chemical analyses given in this memoir.

Climate.

The climate of the area can generally be described as dry and hot. From the end of March to the middle of July is the hot season during

which north-westerly dust-laden winds blow. The summer day-temperature is usually between 105° and 115°F. in the shade, and occasionally 120°F. has been recorded. The monsoon usually sets in towards the middle of June and the rainy season lasts till the end of August or the middle of September. Thence to the middle of March is the cold season, in which there are occasional showers of rain.

The latter part of the rainy season and the earlier part of the cold season are malarious. The period from November to February is the most pleasant and the best time for outdoor work.

Rainfall.

The figures of rainfall, which are recorded at all the police stations in the Gangpur State, vary from station to station. The average annual fall recorded at Sundargarh between 1906 and 1923 has been given as 60·09 inches in a recent publication[1] of the State, the monthly averages being as follows :—

TABLE 1.—*Monthly average of rainfall in Gangpur.*

Month.	Rainfall. (In inches).
January	0·67
February	1·55
March	0·54
April	0·53
May	1·04
June	10·98
July	16·73
August	18·02
September	7·43
October	2·14
November	0·29
December	0·17
TOTAL	60·09

[1] S. N. Khanna, Working Plan of the reserved and protected forests of the Gangpur State Khalsa, (1925-36), 65 pp. (1927). Published by the Gangpur State.

During the last decade for which figures are available, the average rainfall for 13 stations in the State is shown below :—

TABLE 2.—*Annual rainfall in Gangpur from 1923 to 1932.*

Year.	Rainfall.	Year.	Rainfall.
	(Inches).		(Inches).
1923 . . .	61·6	1928 . . .	58·2
1924 . . .	44·8	1929 . . .	74·8
1925 . . .	71·5	1930 . . .	55·2
1926 . . .	59·7	1931 . . .	02·3
1927 . . .	61·4	1932 . . .	59·1

This gives an average of 60·9 inches per year.

During this period, the maximum recorded was 114·5 inches at Lifripara in 1925, while the minimum was 31·7 inches at Bargaon in 1930. In any particular year the figures for the different stations vary considerably.

Flora.

Up to the middle of the last century the area was heavily forested, but since then, uncontrolled cutting by timber-contractors has depleted the State of all good forests. Since 1910, however, the forest management and conservation have been put in charge of a trained forest officer who has, in a large measure, succeeded in demarcating the forest areas and regenerating the forests therein. The forests are at present producing a good revenue which is gradually improving. The area under forest is now between a fourth and a fifth of the total area of the State.

Types of forests.

Three types of forests are distinguished, these being called the 'sal,' 'mixed' and 'bamboo' forests. In the first, *sal* (*Shorea robusta*) forms more than 50 per cent. of the crop, while in the second the percentage of *sal* is less, and the other timber species taken together predominate. The *sal* forests occupy the greater portion of the Nagra *Zamindari* (*i.e.*, the eastern part of Gangpur adjoining Singhbhum), the

Chhatam area south of Rajgangpur, and the Panchra area near the Ranchi border. Forests composed essentially of bamboo, of which *Dendrocalamus strictus* and two or three other species are the most important, are to be found in the hills north of Kurai, in the Dhangarguri area near Masabira, in the Kurumkel area near Rajbahal and in parts of the Chhatam area. The other parts of the State constitute mixed forests.

Timber species.

The species of trees which are of importance as timber, and which are systematically exploited at the present day, are *Sal* (*Shorea robusta*), *Bija* (*Pterocarpus marsupium*), *Kendu* (*Diospyros melanoxylon*), *Gamhar* (*Gmelina arborea*), *Haldu* or *Karam* (*Adina cardifolia*), Laurel, *Sahaj* or *Asan* (*Terminalia tomentosa*), *Siris* or *Kokko* (*Albizzia lebbek*), Axle-wood or *Dhaura* (*Anogeissus latifolia*), *Salai* (*Boswellia serrata*), *Boranga* (*Grewia* sp.), Satin-wood or *Bherwa* (*Chloroxylon swietenia*), Rose-wood or *Sissoo* (*Dalbergia latifolia*), *Jam* (*Eugenia jambolana*), and *Bandhan* (*Ougeinia dalbergioides*).

Useful forest products.

Of these, *sal* is the most important, being much in demand for railway sleepers and for building purposes. Bamboo is locally used for building huts, fences, *etc.*, but its export is limited because of the distance from the railway and the high freight rates. The other timber species are used for a variety of purposes. *Sal* forests seem to thrive well in the valleys and on hill slopes where there is a good supply of water and the soil porous and open-textured. It is generally associated with *sahaj* and *bija*. It seems to have an aversion for basic rocks and for the calcitic and dolomitic marbles. On the other hand, a certain marked preference of bamboo for epidiorite is noticeable, and it also thrives well in the ferruginous sandstones of Himgir. The highly quartzose rocks support a rather stunted assemblage of trees, some of which have pale barks, the characteristic species being *Odina wodier*, *Sterculia urens*, *Gardenia*, *Ficus*, *Euphorbia*, *etc.*

In addition to the forest trees, the *mahua* (*Bassia latifolia*) is to be found cultivated in large numbers in every village. Its petals serve as food, while the seeds yield a useful oil. Several kinds of grass are grown for use in thatching the roofs of huts; the *sabai* grass (*Ischœmum angustifolium*), which grows in the area south of Rajgangpur and the adjoining parts of Bonai, is exported to Calcutta for the manufacture of paper. The *kusum* tree (*Schleichera trijuga*) is important for the production of *lac*. The fruits of *myrobalan*

(*Terminalia chebula*) find use in the tanning industry. The tender leaves of the saplings of *kendu* (*Diospyros melanoxylon*), are collected early in summer and used locally or exported for the manufacture of 'beedies' (tobacco wrapped in these leaves) extensively smoked by the people of India. Mangoes and tamarind are grown for their fruits.

PHYSIOGRAPHY.

This region constitutes an undulating country of varying physical aspect. A good deal of it is a plain with an average elevation of 700 to 800 feet above sea-level. Along the northern border is the Ranchi plateau. The north-western and south-eastern portions are hilly.

The plains.

A belt of country running east and west through the middle forms the plains which are made up of granite and the softer mica-schists. The granitised schists around Sundargarh and to its south form a uniform low plain and similarly the greater part of the Gangpur anticlinorium. The harder rock-bands traversing these plains form hill ranges. The granite region from Sundargarh northward forms a rather undulating plain sloping down towards the south, and joining up with the granite plateau of Ranchi to the north.

Granite plateau.

Along the northern border, the western part constitutes a granite plateau which is physiographically a part of the extensive Ranchi plateau. The average elevation of this is about 1,200 feet. Its boundary with the mica-schists to its south-east is generally marked by a noticeably abrupt descent, as may be seen west of Targa. The border region of the granite and mica-schist is generally hilly.

Rock types and topography.

The mica-schists include varieties which are highly quartzose and hence resistant to weathering. Such bands and others of quartzitic nature are mainly responsible for forming the hills. The crush-conglomerate horizon forming the southern border of the Gangpur anticlinorium as well as the various zones of quartz-schist form the highest hills of the region. Next in importance are the carbonaceous quartzites and epidiorites which also generally form well-marked ranges.

The highest points or peaks in the area are the following:—

	Lat.	Long.
Didrapahar (2,509 ft.)	22° 3′ :	84° 36′ 30″
Bamlopahar (2,498 ft.)	22° 1′ 30″:	84° 30′
Peak west of Jara (2,339 ft.) . .	22° 1′ 30″:	84° 38′
Bhaisamunda pahar (2,234 ft.) . .	22° 2′ :	84° 46′ 30″
Alupahar (2,172 ft.)	22° 30′ :	84° 16′
Burhaparbat (2,146 ft.) . . .	22° 27′ 30″:	84° 5′

It will be noticed that the former four are on quartz-schists and the last two are on epidiorite.

The topography is of the relict type, being controlled by the hardness and resistance to weathering of the various rock formations. It is easily seen that the structure has also a marked influence on it, for the linear trends of the hills follow the general strike of the rocks, though the prominence of the hills depends essentially on the hardness of the individual rocks.

Drainage.

There are three large rivers and several attendant tributary streams in this area. All these flow across the general strike of the formations from north to south, though they are in several places deflected by the hard bands in a direction parallel to the strike.

The Ib river rises in the Jashpur State to the north-west and enters Gangpur near Telijor (22° 21′ : 83° 59′). After taking a broad curve, convex towards the east, it flows past Sundargarh southwards, ultimately to join the Mahanadi in Sambalpur. The major part of its course in Gangpur is through granitic rocks avoiding the uneven mica-schists on either side. Its tributaries are the Ichha, the Baisundar and the Sapai, besides several smaller ones.

The Sankh river traverses the Ranchi plateau before entering this area, and flows in a general south-easterly direction across the Gangpur anticlinorium to Raghunathpali. The Koel comes from the north-east and flows practically parallel to the structure up to Raghunathpali where it joins the Sankh to form the Brahmani. This latter river flows thence southwards through Bonai and other States of Orissa and ultimately empties its waters into the Bay of Bengal.

The softer schists in the region easily form a thick mantle of soil which is in places so extensive that the solid geology has to be interpolated from the exposures available in the neighbouring places. This is especially the case in the eastern end of the anticlinorium where considerable difficulty was experienced in making out the structure.

CHAPTER II.—PREVIOUS WORK.

PREVIOUS LITERATURE.

The following papers deal more or less directly with the geology of the area under description. They are given in chronological order below :—

1855. G. H. Saxton.—Note on specimens of coal and iron from Gangpur. *Jour. As. Soc. Beng.*, XXIV, pp. 185-186, 354-355.

1871. V. Ball.—The Raigarh and Hingir (Gangpur) coal-field. *Rec. Geol. Surv. Ind.*, IV, pp. 101-107.

1875. V. Ball.—The Raigarh and Hingir coal-field. *Rec. Geol. Surv. Ind.*, VIII, pp. 102-121.

1877. V. Ball.—On the diamonds, gold and lead-ores of the Sambalpur district. *Rec. Geol. Surv. Ind.*, X, pp. 186-192.

1881. V. Ball.—A manual of the Geology of India, Part III—Economic Geology, pp. 90, 195, 200, 460.

1884. W. King.—On the selection of sites for borings in the Raigarh-Hingir coal-field. First notice. *Rec. Geol. Surv. Ind.*, XVII, pp. 123-130.

1885. W. King.—Sketch of the progress of geological work in the Chhattisgarh division of the Central Provinces. *Rec. Geol. Surv. Ind.*, XVIII, pp. 169-200.

1886. W. King.—Boring exploration in the Chhattisgarh coal-fields. *Rec. Geol. Surv. Ind.*, XIX, pp. 210-234.

1901. F. H. Hatch.—Report on the auriferous quartzites of Pahardiah, Chota Nagpur. *Mem. Geol. Surv. Ind.*, XXXIII, Pt. 2, pp. 68-71.

1902. C. L. Griesbach.—General Report of the Geological Survey of India for 1901-02, pp. 10-13.

1903. T. H. Holland.—General Report of the Geological Survey of India for 1902-03, pp. 10-14.

1904. J. M. Maclaren.—The auriferous occurrences of Chota Nagpur, Bengal. *Rec. Geol. Surv. Ind.*, XXXI, pp. 59-91.

1909. L. L. Fermor. Manganese-ore deposits of India. *Mem. Geol. Surv. Ind.*, XXXVII, p. 615.

1909. T. H. Holland. General Report of the Geological Survey of India for 1908. *Rec. Geol. Surv. Ind.*, XXXVIII, p. 43.

1911. L. L. Fermor. Notes on the manganese-ore deposits of Gangpur State, Bengal, and on the distribution of the Gondite series in India. *Rec. Geol. Surv. Ind.*, XLI, pp. 12-21.

1919. L. L. Fermor. Some problems of ore genesis in the Archæans of India. (Presidential address to the Geology Section, Sixth Indian Science Congress.) *Proc. As. Soc. Beng.*, *N. S.* XV, p. clxxxi.

1925. E. Spencer. Albite and other authigenic minerals in limestone from Bengal. *Mineral Mag.*, XX, pp. 365-381.

General Reports of the Geological Survey of India for the successive years from 1928 to 1933:

1929. *Rec. Geol. Surv. Ind.*, LXII, pp. 96-98.
1930. *Op. cit.*, LXIII, pp. 82-85.
1931. *Op. cit.*, LXV, pp. 73-75.
1932. *Op. cit.*, LXVI, pp. 83-85.
1933. *Op. cit.*, LXVII, pp. 63-66.
1934. *Op. cit.*, LXVIII, pp. 81-82.

V. Ball.

The geology of the region was first studied in connection with the economic mineral deposits, as has been the case with many other areas in India. Saxton's account of the occurrence of coal in Gangpur drew the attention of the Geological Survey Department to this area. Ball conducted a preliminary survey in 1870 and recognised the presence of the Talchirs, Barakars and Hingir sandstones. He also recognised an older series of rocks which he referred to the Vindhyans. In his accounts he described the different coal exposures and generally indicated the distribution and extent of the coalfield. This was followed soon after by a bore-hole exploration by W. King with the

W. King.

assistance of Hiralal. We have therefore fairly complete information about the Gondwanas, which however have not been included in the present mapping, though a few observations made in them along their junction with the metamorphics are recorded here for the sake of completeness.

Some measure of attention was again accorded to this region and the adjoining parts of Chota Nagpur during or soon after the time of the gold boom just at the dawn of the present century. F. H. Hatch reported on the gold occurrence at Pahardia, which lies at the north-easternmost corner of the area under description in the present memoir. Later, F. H. Smith and J. M. Maclaren conducted an examination of the area for gold. They recognised the general rock formations here as belonging to the Dharwars. Griesbach, in his annual report of the Geological Survey of India for the year 1901-02 (p. 10), has given an extract from F. H. Smith's progress report of that year's work :—

Hatch, Smith and Maclaren.

'The geology of the area is very simple on the whole. The rocks consist of the schists and slates of the Transition System, with a very constant east and west strike, and dip varying from vertical to 50°N. At the same time there is a good deal of local crushing of the beds with frequent evidence of faulting on a limited scale. In the hilly country the rocks are traversed by well-defined sets of cleavage and joint planes.... The most common type (of rock) is a soft greenish clay-slate, locally steatitic or sandy. The harder rocks consist of chloritic, micaceous, hornblendic and hæmatitic schists with thin bands of compact felsite. They show, under the microscope, signs of great crushing and metamorphism, having a general epidioritic appearance, with a few strings and trails of mylonitic quartz fragments and minute crystals of chlorite or mica, and some secondary calcite. Occasional beds of compact dolomite occur, and also bands of segregated hæmatite and quartz-hæmatite breccia, in the slates.'

The above concise, though sketchy, description of the geology was followed by one, more comprehensive and detailed, by J. M. Maclaren in connection with his description of the gold occurrences of Chota Nagpur. He wrote[1] :—

'The great bulk of the rocks of the auriferous country must be assigned to the Archæan Dharwarian Series, formerly included in and known as the Transition Series, so largely developed in Southern Peninsular India. The correlation of the Chota Nagpur rocks with those of Southern India rests entirely, or almost so, on the correspondence of lithological characters, but this correspondence is so complete as to leave little doubt of their geological contemporaneity. The most prominent members of the series in this area are argillites, phyllites, mica-schists, talc-schists and quartzites. The first and second appear to have their greatest development in the south of the region occupied by the Dharwarian series, *i.e.*, in the south of Singhbhum and the east of Gangpur ; while from the greater schistosity of the rocks of the series to the north, it is evident that there the agencies of metamorphism have been either more intense or have acted through a longer period of time.

[1] J. M. Maclaren, The auriferous occurrences of Chota Nagpur, Bengal. *Rec. Geol. Surv. Ind.*, XXXI, p. 70, (1904).

Speaking in general terms, it may be said that the amount of schistosity is inversely proportional to the distance from the granites and gneisses which bound the Dharwarian rocks to the north.'

Again he stated[1] :—

'As one result of the season's work in Chota Nagpur, the boundaries of the Dharwarian series were extended considerably to the west and south-west, into the Native States of Gangpur, Bonai, Jashpur and Udepur. This area has heretofore been mapped as belonging to the gneissic and crystalline series. The greatest development of the schistose rocks here lies along the Ib river and along its tributaries, mainly the Icha. Though the gap of 20 miles lying between these rocks and those of the main Chota Nagpur mass was not bridged, yet the latter were brought down as far as Bamra, on the Bengal Nagpur Railway,— so far indeed as to leave little doubt of the continuity of the Dharwarian series from Simalpal, in Bankura, to at least the boundary of the Udepur State, a distance of 180 miles. The maximum breadth of the band is probably about 50 miles.'

Though Maclaren has clearly recognised the rocks in this area as belonging to Dharwar age, yet the presence of limestones, phyllites and conglomerates in the band of rocks just north of the railway for a long distance in Gangpur seems to have led him to regard them as Cuddapahs. The relevant passages are extracted below[2]:—

'From near Jaraikela to Bamra and parallel with and at a distance of one to three miles from the Bengal Nagpur Railway, is a series of sandstones, grits, shales, limestones, the first containing in places highly ferruginous deposits. The dip of the whole is extremely high, and generally to the south. Near Raghunathpali, these beds are exposed in the Koel river where they are composed of shales and of grey compact limestones, all dipping to the south at an angle of 60° and over. '

On the same page, further on, a passage from an unpublished progress report of F. H. Smith is quoted :—

'The sandstone and grit is of a peculiar grey-greenish colour and it strongly resembles the lowest Cuddapah beds in the Barapahars, to the north-west of Sambalpur. The whole facies of the rocks of these two localities is very similar, and it seems probable that the Bisra belt is a band of Cuddapah age which has here become folded into the underlying Transition rocks.'

From the above it is clear that Maclaren, led by lithological similarities, regarded all the succession south of the Koel river and the corresponding portion further west as belonging to the Cuddapah system.

[1] *Ibid.*, p. 72.
[2] *Ibid.*, p. 73.

At an earlier period, V. Ball noticed the limestones in the Sapai *nadi* at Kinjirma, which he described under the 'Metamorphic series' as follows[1]:

> 'The last section in the tract of country which there is space to notice here, is that afforded by the (Gangpur) Sumpai, a tributary of the Ebe. Close to Kujerma the bed of the river discloses a thickness of 50 to 60 feet of blue limestone, dip 40° south-south-east. Underneath these, are somewhat sandy quartzites, and the two rocks taken together are not unlike the Vindhyans seen near Padampur (on the Mahanadi). Nearer the village, however, these rocks appear to be conformable to and dip under granitic gneisses, which are in close proximity; but no actual junction is seen. A portion of the limestone is of inferior quality, containing tremolite; but much of it is a strong pure rock, which ought to prove valuable, should occasion arise for its employment. The same limestone is seen near the junction of the Sumpai with the Ebe, where it occurs in horizontal beds, abutting against a vein of coarse granite.'

Thus Ball regarded the limestones as belonging to the metamorphics though suggesting the similarity to the Vindhyans.* As shown above, Maclaren and Smith, who worked further east, thought the same zone belonged to the Cuddapahs. This latter view has been persistently, though perhaps unconsciously, adopted by the Geological Survey in referring to these limestones in the successive quinquennial reviews of mineral production issued by the department; and this, in spite of the fact that Sir Lewis Fermor examined the manganese-ore deposits at Ghoriajor in 1908 and assigned all the rocks occurring in the section between Dharuadihi railway station and Ghoriajor, including the marbles, to the Dharwars, as will be seen from the extract given below[2]:—

Sir Lewis Fermor.

> 'This direction (*i.e.*, the north-east) corresponds roughly with the strike of the Dharwar schists, with which the manganese ores are associated, and which occupy the whole of the ground between Garinjhor mine and Dharuadihi (except where they are obscured by soil and laterite, itself often manganiferous). These Dharwars comprise mica-schists, mica-phyllites, quartzites, and grey dolomites, the latter being exposed at the crossing of the Sampai river.'

[1] V. Ball, on the Geology of the Mahanadi basin and its vicinity. *Rec. Geol. Surv. Ind.*, X, p. 182, (1877).

* The Vindhyans referred to by Ball, in parts of Orissa and the Central Provinces are, according to the present views of the Geological Survey of India, to be regarded, for the most part, as Cuddapahs. They are shown as such in the recently published geological map of India (Scale 1 inch = 32 miles, 1932), and also in Sir Lewis Fermor's paper on the 'Mineral Resources of the Central Provinces' (*Rec. Geol. Surv. Ind.*, L, pt. 4, 1919)

[2] L. L. Fermor, Notes on the manganese-ore deposits of Gangpur State, Bengal, and on the distribution of the Gondite series in India. *Op. cit.*, XLI, p. 13, (1911).

The result of the present survey has been to show that all the rocks, including the limestones, dolomites and conglomerates, are of Dharwar age, besides indicating that the structural unit in Gangpur is older than the Iron-ore series of Singhbhum which has also been recently established as part of the Dharwars by Mr. H. C. Jones and Dr. J. A. Dunn.

Dr. J. A. Dunn.

Dr. Dunn[1] divides the Iron-ore series in Singhbhum into four stages, of which one, the Chaibassa stage, consisting of argillaceous rocks, limestones and basal sandstone-conglomerate, lies below his Iron-ore stage. He mentions discordances and overlap within the Iron-ore series, between these several stages.

He would now prefer not to use the term 'Dharwar' as applied to the Archaean rocks of Singhbhum, and so avoid possible confusion. He is also of the opinion that the Gangpur series should not be definitely assigned to a lower position than the base of the Iron-ore series. Within the Iron-ore series there are known overlaps, and, whilst admitting the possibility of my view, he is of the opinion that the position for the Gangpur series between the basal Chaibassa stage and the Iron-ore stage is equally probable. The structure associated with the Gangpur group of beds is so complicated that a final decision seems most difficult.

With regard to the intrusive rocks, Maclaren considered the epidiorites younger than the pegmatites and granites which he observed in the valley of the Ichha *nala* and other places. The reverse, however, happens to be the case. The epidiorites, which are considered to be of Cuddapah age, are also credited with being the source of the gold, for Maclaren believes that the hydrothermal quartz-bearing solutions which carried the gold were initiated by the basic intrusive, a view which is not likely to meet with much support at the present day. Summaries of the results of each year's work of the writer have already appeared in the successive annual reports of the Geological Survey of India for the years from 1928 to 1933.

[1] "The Mineral Deposits of Eastern Singhbhum and Surrounding Areas," *Mem. Geol. Surv. Ind.*, LXIX, Pt. 1, pp. 45-48, (1937).

CHAPTER III.—GENERAL GEOLOGY.

GEOLOGICAL SUCCESSION.

The published work dealing with this area has been of little help beyond giving a rough idea as to the nature of the different rocks occurring here. As the work of mapping progressed, knowledge was gained of the succession of the rocks and structure. The following sequence in the descending order is now established:—

Recent	Superficial laterite and alluvium.
Gondwana system . . .	Hingir sandstones (Kamthi-Raniganj). Barakars. Talchirs.
	Unconformity.——
	Granite, pegmatite and vein-quartz. (Main period of diastrophism.)
Upper Dharwar, Iron-ore series .	Basic igneous rocks, now amphibolite and epidiorite. (? Older granite-gneiss.) Mica-schists and phyllites with quartzite and carbonaceous phyllite zones.
	Sheared conglomerate (? zone of thrust)— — (Raghunathpali stage).
Middle Dharwar, Gangpur series	Mica-schists and phyllites with a zone of carbonaceous rocks. (Laingar stage). Calcitic marble, Dolomitic marble (Birmitrapur stage). Mica-schists and phyllites with a zone of carbonaceous rocks. (Kumarmunda stage). Phyllites with gonditic rocks. (Ghoriajor stage). (Base not seen.)

I have proposed the name *Gangpur series*[1] for the assemblage of beds found in the Gangpur anticlinorium and its western extension, comprising the members given in the above table. The oldest rocks, which occur in the centre of this anticlinorium, are phyllites and mica-schists containing thin beds and lenses of gondite rocks very similar in nature to those of the Central Provinces. Their exposures are restricted to a small number of places with Gobira as the easternmost, and Ghoriajor as the westernmost occurrence.

Gondites.

[1] *Rec. Geol. Surv. Ind.*, LXVII, p. 64, (1933).

After an interval marked by mica-schists, appears the lower carbonaceous phyllite zone, which has been found to be of great help in deciphering the structure of the region. It is found right around the anticlinorium but becomes indistinct further west. This is followed by more phyllites which are overlain by the marbles. The lower portion, in general representing more than half and nearly two-thirds of the total thickness, is of dolomitic composition, while the upper portion is mainly limestone with some minor magnesian bands. This marble zone is much broken up at the eastern end of the anticlinorium but is a fairly conspicuous and very important zone in middle and western Gangpur. Indeed the occurrence of this zone in the western area (near Lifripara) has been of great importance in deciding on the age of the associated rocks there.

Carbonaceous phyllites and marbles.

This is in turn overlain by more phyllites and an upper carbonaceous zone. In several places the carbonaceous rocks have been invaded by sills of basic rocks of later age, in the anticlinorium.

At the top of the Gangpur series is the well-marked zone of crushed and sheared conglomerate, seen over a length of some 60 miles from Kolpotka and Sirka on the east to Amasranga near Ghoriajor on the west. On the northern side of the anticlinorium, this zone is marked by less easily distinguishable and impersistent quartzite bands grading into quartzose mica-schists.

Sheared conglomerate.

It is not quite clear which portion of the Iron-ore series is represented here—whether that above the banded haematite-jasper or below it. Probably it is the lower portion. It comprises all the strata above the zone of crush conglomerate mentioned above, and some bands of quartzites (including conglomerates and grits) and carbonaceous phyllites. The carbonaceous rocks however do not form very definite zones but are only locally developed. In the northern area, including that to the north of Lifripara, there are several bands of basic rock, appearing as sills in the series. It is possible that in the north-east there are also contemporaneous lava flows and perhaps even tuffs, but in an area so much subjected to folding and metamorphism, the flows are difficult to distinguish from sills. In the south-east also there are a few sills in the Iron-ore series.

Basic rocks.

The basic rocks increase in abundance towards the north-east end of the area, *i.e.*, in the direction of the Dalma region in North

Singhbhum. The Dalma traps, of which these are undoubtedly the extensions, have been assigned to the top of the Iron ore series by Dr. J. A. Dunn[1], who has also shown that these rocks in North Singhbhum are mainly of the nature of flows accompanied some times by pyroclastics.

There are a few small patches, around Jara in the south eastern part of this area, of pink granitic gneisses which appear to be intruded into by epidiorites. The field evidence is rather inconclusive. They however appear to be of a somewhat different nature to the other masses of granite found more to the north. Hence they may be tentatively considered to represent an older granite.

All the above belong to the Dharwarian age, since they have been subjected to the intense folding and regional metamorphism which took place towards the close of the Dharwarian era. But the large granite masses of Ranchi with their extensions in Gangpur, including the three separate bosses, as well as that in Bonai, of which only a very small fraction is seen in the south-eastern corner of the present region, all belong to a later age. Towards the margins they show composite and hybrid gneisses and have granitised large areas of old mica-schists. They are the equivalents of, or are identical with, the granites of Singhbhum and Keonjhar, which Sir Lewis Fermor considered, because of some differences in the observed characters, as possibly representing rocks of different periods of intrusion[2]. But, so far as the present area is concerned, all the granites and gneisses, except for the few exposures near Jara, seem to be of the same age, and that younger than the period of diastrophism at the close of the Dharwars.

Granite.

There are no formations to fill the enormous gap represented by the ages between the Dharwars and the recent deposits. These latter consist of superficial alteration products of the rocks and comprise laterite, soil and alluvium. But in the south-west occur rocks of Gondwana age, to the borders of which the present mapping was carried. The few observations that were made on these Gondwana rocks, comprising here the Talchirs, the Barakars and the Hingir sandstones (Kamthi) are, however, recorded in the present memoir.

[1] J. A. Dunn, Geology of North Singhbhum including parts of Ranchi and Manbhum districts, *Mem. Geol. Surv. Ind.*, LIV, p. 12, (1929).

[2] T. H. Holland, General Report of the Geological Survey of India for 1908. *Rec. Geol. Surv. Ind.*, XXXVIII, p. 18, (1909).

GEOLOGICAL STRUCTURE.

A general review of the structure is given here to enable the reader to grasp the essential features of the area. The details of the distribution of the different stratigraphical units and their characters will be given in later chapters.

Structurally the area can be divided into two major divisions, which roughly correspond to the geological units. Of these the first is the Gangpur anticlinorium extending in an E. N. E.—W. S. W. direction from the Singbhum border on the east to the Sambalpur border on the west. All the members of the Gangpur series are contained in this, but the two carbonaceous zones with the marble zone between them are the most helpful in showing the general behaviour of the outcrops. The southern limit of this series coincides with the Raghunathpali conglomerate which lies parallel to, and at a short distance north of, the railway track. The anticlinorium pitches towards the east and the pitch phenomena are best seen all along the eastern exposures of the older carbon-phyllite zone. This shows a series of repeated folds, the southernmost two of which pass into shear-faults. The pitching phenomena are also seen in the marbles and the younger carbon phyllites, but only at a few places are they exposed well without interference from soil cover. The influence of the pitch of this structure is also seen nearly as far out as Anandpur in Singhbhum. The eastern end is therefore a closed structure where every one of the members of the Gangpur series can be traced back from one limb into the other, in spite of the widespread soil cover.

Anticlinorium.

The southern limb can be traced up to Laingar wherefrom it proceeds further west, but is folded back and again forth, finally continuing in a W. S. W. direction to as far as the Ib near Bhasma. The northern limb is more highly compressed and is also truncated or pinched out to the west. The well-marked synclinal fold at Dublabera and Saromohan is easily noticed. Its northern limb is the reflexed northern limb of the anticlinorium. It is again bent back as the southern limb of the Dublabera syncline but can be followed only for a few miles westward where the individuality of the beds

is lost. The north-western boundary of the anticlinorium is difficult to trace because of the intense compression and partial pinching out of the upper beds (including probably a small part of the Iron-ore series) which may have been brought about by the intrusion of the granite batholith. Further uncertainty is due to the presence of two granite bosses which have completely displaced the original schists.

In the southern limb there is what appears to be a comparatively small double knee-bend in the neighbourhood of the Mahabirpahar near Purkapali. This is well seen in the sheared conglomerate band. It will be noticed also that the marble band here is exceptionally wide -over a mile wide in fact— and this is obviously due to this close double kink in it. In the Ghoriajor region, the conglomerate zone is seen at Amasranga, the marbles along the Sapai *nadi*, the carbon-phyllite (evidently the older zone) at Jarmal and the gondites at Ghoriajor and Manomunda. Beyond Ghoriajor, only the marbles are traceable with certainty, the others being inconspicuous and perhaps obscured by, or lost in, the extensive granitisation.

Western area.

After an interval of a few miles, this series, of which the intrusive granite has obliterated the individuality, can again be traced from near Sargipali west-north-westwards to Sarapgarh and beyond. The two boundaries of the series seem to be the large hills of micaceous quartz-schists on each side of the valley of the Ichha *nala*. The southern boundary is gradually overlapped by the Barakar rocks in a westerly direction. Inside this area is a thin band of dolomitic marbles exposed at Lifripara and Surgura, which probably represents the core of an anticline, for neither gondite nor the carbonaceous zones are to be seen here.

Strike.

It is also to be noted that the Gangpur series, which has a general E. N. E.—W. S. W. strike in the area east of the Ib, shows a veering round to a W. N. W.—E. S. E. strike beyond and to the west of that river in the Sarapgarh area. It presumably continues westwards, underneath a cover of Gondwanas and Cuddapahs, into the strip of Dharwars in the Balaghat district of the Central Provinces. The Lifripara exposures reach up to longitude 83° 40′, while the easternmost outcrop of the Dharwars in the Central Provinces is found at longitude 82° 20′. The distance between the two is thus about 100 miles.

The rocks surrounding the anticlinorium and those to the north of the Lifripara strip, all belong to the Iron-ore series. The north-easternmost of these is full of basic sills (perhaps including flows) and becomes very much compressed and constricted when followed westwards. This is well seen in the narrowing of the basic sills and of the intervening phyllites when followed from east to west. The series of rocks exposed at the eastern end comes to occupy barely a third of its width near the border of the granite. In this strip there is more than one distinct fold, a synclinal axis passing through Parba and Targa. The general southerly dips in the rest of the area may be due to the presence of tightly packed isoclinal folds.

Area surrounding the anticlinorium.

Further west, in the granite mass, there are bands of mica-schists and of banded gneisses which seem to have preserved the structural disposition of the original schists. There are indications that the Talsara and the Bandega bands of granite occupy anticlinal structures, while the strip of schists in which the Burhaparbat lies forms a well-marked syncline.

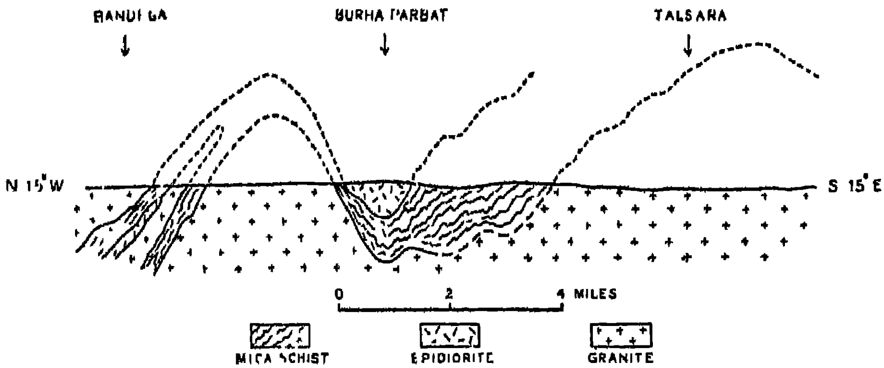

FIG. 1.—Section across the granite plateau from Talsara to Bandega.

Still further west, *i.e.*, beyond the Talsara granite area, is the dissected high land north of Lifripara. This shows a succession of phyllites and mica-schists with a few epidiorite sills, all thrown into folds. A shear zone, apparently extending from Matipahar to Kinjirkela, traverses this in a direction more or less parallel to the strike.

The eastern end of the anticlinorium pitches under the succession of the phyllites of the Anandpur area. These phyllites are to some

extent affected by the pitches; but further out, from near the course of the Koel river, begin to assume the general E. N. E. W. S. W. strike. The band of quartzite which strikes N. N. E. from the Gangpur-Ranchi-Singhbhum trijunction seems to mark a fold fault; in any case it seems to have no connection with the Raghunathpali conglomerate zone.

South-eastern area.

To the south and south-east of the anticlinorium the phyllites show a marked syncline whose axis passes roughly through Mundajor on the east and Rabga in Bamra State on the west, and extending further out at both ends. Sharp minor folds are frequently seen in the area south of Kalunga. One particular feature to which attention may be called, is a southward buckling of the folds in this area, clearly seen in the carbon-phyllite beds around Rangamati (22° 2′ : 84° 49′). These show a marked bend, convex to the south, in the region of longitude 84° 50′.

The generally prevalent southerly dips in practically the whole of the anticlinorium proper (except the northern border) which change slightly to E. S. W. at either end, show that the rocks have been subjected to very close isoclinal folding.

On the north-west, the beds have been folded tightly back on themselves. Except in the south and south-east where low dips prevail, the dips are generally quite steep. The greater part of the area must therefore have been subject to intense pressures in a nearly north to south direction during a period of orogenesis, followed by the invasion of the granite batholith. During the compression, attended undoubtedly by shearing phenomena, the hard rocks have been crushed, while the softer ones have been milled and transformed into fine schists. Some differential movements of larger or smaller magnitude are also likely to have taken place, especially along the shear-zones. So that the Raghunathpali conglomerate zone on the south and its equivalent on the north (quartzites and micaceous quartz-schists) very probably mark a zone of differential movement. It is also to be remarked that, since the beds involved are very steeply dipping and in places nearly vertical, and since the rocks on both sides of the shear zones are lithologically similar, the evidence of overthrusting and overriding is practically impossible to detect.

A sketch map showing the connection between the different outcrops of the chief formations in the anticlinorium is given in Plate 18, as it is hoped that such a simplified map will help in

understanding the geological map more readily. Sections across the structures are also given with the geological map, Plate 19.

Faults.

It has already been suggested that the Raghunathpali conglomerate zone in particular, and possibly some of the other gritty and conglomeratic bands, may indicate zones of thrusting and shearing. In addition to these there are a few distinct bands of fault breccias enumerated below, which seem to indicate zones of faulting.

1. An E.-W. trending hillock a mile to the north of Bandega.
2. The Matipahar and hill to its east, on the Jashpur border.
3. From Sundargarh north-westwards to Patrapali.
4. From Tinkura to Rainda through Mangaspur.
5. Crushed pegmatite zone passing through Kinjirkela.

These fault breccias are described in a later chapter.

The pitching eastern end of the anticlinorium shows two shear-faults in the lower carbonaceous phyllites near Rukedega and east of Kumarmunda.

Lastly may be mentioned the portion of the course of the Sankh and its two tributaries on either side, which together form a remarkable straight line between Dhondijor (22° 25′ 30″ : 84° 10′) and Rangadipa (22° 29′ 30″ : 84° 21′ 30″). This may be a fault line or perhaps merely a major joint.

RELATIONSHIP BETWEEN THE GANGPUR SERIES AND THE IRON ORE SERIES.

The Gangpur series is surrounded on all sides by the mica-schists and phyllites of the Iron-ore series. In the north-east, *i.e.*, near Hathibari and further east, the marbles and the younger carbon phyllites assume a southerly dip, which is apparently due to an overfold. Hence the members of the Iron-ore series look as if they underlie the carbon-phyllite, though a few miles further west the normal order of superposition is seen. Further north the series is sharply folded.

At the eastern end, the Iron-ore series overlies the pitching rocks of the anticlinorium with conformable dip. The effect of the pitch gradually dies down by about longitude 85° 15′. In the confused mass of hills of the Anandpur region and the Gangpur Singhbhum border, the individual beds are not clearly defined though there are sufficient indications to enable us to make out the structure.

In the south-east, the steep dips of the Raghunathpali conglomerate are continued for a few miles to the south where a syncline intervenes, beyond which steep north-north westerly dips prevail. The centre of the syncline shows rocks with nearly vertical dips. Further east, in South Singhbhum, there are beds of banded haematite-jasper, which seem to overlie these presumably overfolded phyllites. The sequence of beds in the South Singhbhum area is isoclinally folded, as will be seen from the map accompanying Mr. H. C. Jones' memoir[1] describing this area. There are some striking lithological differences between the Gangpur series and the Iron-ore series :

1. Gonditic rocks occur in the lowest horizon in the former. They occupy a fairly defined stratigraphical position. In the Iron-ore series there are, so far as our knowledge goes, locally manganiferous shales, from which manganese

[1] *Mem. Geol. Surv. Ind.*, LXIII, Pt. 2, (1934).

ores have been segregated (*e.g.*, at Tutugutu near Chaibasa and at Bara Jamda and Barabil on the Singhbhum-Keonjhar border). These shale horizons moreover do not belong to stratigraphically identical horizons.

2. There are two persistent horizons of carbonaceous phyllite in the Gangpur series. Though such rocks occur in the Iron-ore series they are of comparatively local development and are not seen continuously for long distances.

3. The calcitic and dolomitic marbles again form a very definite stratigraphic unit in the Gangpur series. In the Iron-ore series there are limestones and carbonaceous shales only locally developed near the basal portion. This is similar, for instance, to the occurrence of the limestone and calcareous phyllite band of Dhelsara rather than to the main marble band.

4. Beds of banded haematite-jasper are present in the Iron-ore series in South Singhbhum, which have no representatives at all here. In North Singhbhum some haematite-quartzites and haematite-schists have been found by Dr. Dunn but they are of subordinate importance.

5. In the Iron ore series, the basic rocks have been considered to be mainly of the extrusive and pyroclastic facies by Dr. Dunn. In the Gangpur series all the basic rocks occur as sills. In the Iron-ore series occurring in the Gangpur area, there are only the chloritic conglomerates and grits which can be said to be pyroclastic; in the Ranchi portion of the present area the epidiorite bands do not seem to be associated with flows or pyroclastics. In any case, the proof that such exist is extremely difficult to establish.

If we add to the above evidences that of the structural relationship, there is little doubt that the Gangpur series is older than the Iron-ore series. Whether the two series represent the products of a single continuous period of deposition or whether there is a decided break between the two is apparently a problem difficult of solution. The conglomerate horizon between the two, along the whole of the southern border of the anticlinorium, would probably indicate an intraformational break in sedimentation.

CORRELATION.*†

Reasons have already been given for considering the Gangpur series as distinct from and older than the Iron-ore series. In the adjoining area in South Singhbhum, the Iron ore series shows a basal conglomerate resting on the upturned and denuded edges of an older series composed of quartzites and hornblende schists, the latter undoubtedly of igneous origin. This older metamorphic series,[1] to which the name older Dharwars may be given, always shows very steep dips and is overlain by various members of the Iron-ore series with a profound unconformity between. The magnitude of the unconformity between the Gangpur series and the Iron-ore series is not known, but it seems to be appreciable since the lower beds of the latter are not seen.

The above facts would indicate that the Dharwars of the Chota Nagpur area may be separable into three divisions:-

(3) Iron-ore series
(2) Gangpur series
(1) Older metamorphic series

In the area occupied by the Dharwars in the Nagpur-Chhindwara-Bhandara region of the Central Provinces two main divisions of the rocks can be recognised, which, as pointed out by Sir Lewis Fermor,[2]

* This subject is dealt with in greater detail in the author's Presidential address to the section of Geology, Twenty-second Indian Science Congress, Calcutta, 1935.

† Commenting on this section, Sir Lewis Fermor remarks :- ' There is apparently a profound unconformity between the Older Metamorphic series and the Iron-ore series, and unless the Gangpur series is treated as occupying, to the west, this stratigraphical gap, there is presumably also a marked unconformity between the Gangpur series and the Older Metamorphic series. Whilst agreeing that the Iron-ore series and the Gangpur series are the equivalents of the Dharwars of Southern India, I am doubtful whether the Older Metamorphic series should be so included or instead treated as representing a formation older than the Dharwars. This is, of course, a point undecided, and the author is entitled to his own opinion '.

The Older Metamorphic series is meagrely exposed in South Singhbhum, and in addition to the profound unconformity, there is marked difference in lithology and metamorphism between this and the younger series. Hence there can be no serious objection to treating the Older Metamorphic series as older than the Dharwars.

Since this memoir was written, Mr. B. Rama Rao, Director of the Mysore Geological Department, has described (Presidential address to the section of Geology, Twenty-third Indian Science Congress) the major iron-formations of Mysore—corresponding to the Iron-ore series—as belonging to the Middle Dharwars. Under his scheme also the Older Metamorphic series will evidently be relegated to a pre-Dharwar age.

In a question of such complexity, all that can be said at present is that my view put forward here is a possible one, subject to modification as more knowledge accumulates.

[1] J. A. Dunn, The Geology of North Singhbhum, including arts Ranchi and Manbhum districts. *Mem. Geol. Surv. Ind.*, LIV, pp. 14-16, (1929).

[2] *Rec. Geol. Surv. Ind.*, LXVII, pp. 64-65, (1933).

seem to be the equivalents of the Gangpur and Iron-ore series respectively. The older of these two, named the Sausar series,[1] has been divided by him into several stages containing gondites, dolomitic and calcitic rocks and their metamorphic derivatives. The gondite horizon, comprising the Mansar stage, is here underlain by two stages, mainly composed of calc-marbles, calc-granulites and hornblende-biotite-granulites. Above the Mansar stage is a complex assemblage of metamorphosed dolomitic rocks and basic igneous rocks. A general correspondence of the Sausar series with the Gangpur series can thus be seen. In the triangular area in the Bhandara district, to the south of the above, there is exposed a series of rocks, also of Dharwar aspect, but generally composed of phyllites, haematite-quartzites, shales, *etc.* This, the Sakoli series, bears a resemblance to the Iron-ore series and may be considered as its equivalent. The Sonawani series of Burton in the Balaghat district is the equivalent of the Sausars while the Chilpi Ghats resemble the Sakolis. So that, in the belt of Dharwarian rocks stretching from Singhbhum on the east to Nagpur and Chhindwara on the west, the more northerly areas in general belong to an older series and the southern areas to a younger series, the younger rocks here and there overlapping the older ones.

Between the Dharwarian tract of Jubbulpore[2] and that of Chota Nagpur also there is a great deal of similarity. In Jubbulpore also calc- and dolomitic marbles, manganiferous rocks, banded haematite-jaspers and epidiorite sills occur, so that the equivalents of both the Sausars and Sakolis are apparently present. The structural relationships of the rocks of this region have however not been worked out in detail, though it is known from the work of the authors referred to, as well as from my own recent observations, that the very close isoclinal folding and overfolding observed here are of great complexity.

All the above are probably parts of one huge basin of geosynclinal sedimentation in the Dharwarian era, during which the rocks deposited in the different parts have had similar lithological characters. From the data available at present, it is not possible to

[1] General Report of the Geological Survey of India for 1925. *Rec. Geol. Surv. Ind.*, LIX, pp. 76-80, (1926).

[2] C. A. Hacket, Manuscript report (unpublished) of the work of the Season 1870-71.
P. N. Bose, The manganese-iron and manganese ores of Jabalpur. *Rec Geol. Surv. Ind.*, XXI, pp. 74-89, (1888); XXII, pp. 216-226, (1889).
L. L. Fermor, The Manganese-ore deposits of India. *Mem. Geol. Surv. Ind.*, XXXVII, pp. 804 *et seq.*, (1909).

state whether rocks similar to the older Dharwars of Singhbhum occur in the Central Provinces, but such a possibility does exist. There seems to be little doubt that the upper two series are present in all these areas, judging from their lithological and structural resemblances.

Tectonics.

From the description given in the chapter on 'Structure', it will be clear that the anticlinorium contains the oldest rocks of the area under consideration. The structure is a closed one on the east, but is much obscured on the west by granitic intrusives. Still further west, in the Lifripara area, the Gangpur series is overlapped by younger rocks, including the Gondwanas.

The general direction of the fold-axes in the anticlinorium is E.N.E.-W.S.W., locally changing to E.-W. The compression has therefore acted in approximately a N.-S. direction.

Along the southern and south-western border of the area, a second direction is prominently seen, *viz.*, W.N.W.-E.S.E. This can be seen in the Lifripara area and in parts of Bonai and Bamra included in the map. This direction continues east-south-eastwards along the Mahanadi valley from western Gangpur and Bilaspur down to the Eastern Ghats near Cuttack.

A third direction of strike (N.N.E.-S.S.W.) which is characteristic of the Iron-ore series of South Singhbhum and of the rocks of the Eastern Ghats, is seen along the eastern edge of the area, though it is affected to some extent by the strike of the anticlinorium.

In the rocks of the anticlinorium and the immediate vicinity there are clear evidences of two periods of movements. This is particularly well brought out by the relationship of the porphyroblasts to the schistosity in the mica-schists, by the superposition of an epi-grade on a former meso-grade metamorphism and perhaps also by the shear phenomena seen in certain beds. The direction due to the later movement is the one prominently displayed in the anticlinorium while that due to the earlier movement is not possible to deduce from the data available at present. For this it will be necessary to study carefully oriented sections from rocks collected with reference to their orientation in the field.

All these periods of compression must have preceded the intrusion of the granite, for the latter has not been affected by any of them. The two movements of which evidence is found in the anticlinorium seem also to be later than the epidiorite.

Metamorphism.

In the south-eastern and southern parts of the area the rocks have been subjected to a low grade of metamorphism, but it has been more intense in the anticlinorium. In the latter, there is evidence of the meso-grade in the presence of garnet and staurolite in the mica-schists, and tremolite and diopside in the marbles. The development of garnet- and pyroxene-bearing hornfels in a few places indicates localised intensity of the phenomena. In the whole of the anticlinorium, however, an epi-grade metamorphism has been superposed on an earlier higher grade so that the mica-schists now appear as phyllites, with the development of chlorite, while the basic igneous rocks have been converted into amphibolite and epidiorite.

The sequence of events constituting the geological history of the area may be summarised as follows: On an area underlain by the Older Dharwars there were laid down sediments of considerable thickness. Among the earliest of these were manganiferous materials derived evidently from previously existing rocks. Later still were deposited carbonaceous clays, dolomite and limestone and again carbonaceous clays, in succession, ordinary clay forming intercalations between the several members. Whether this succession, which forms the Gangpur series, was compressed and elevated prior to the deposition of the Iron-ore series is not clear, but the presence of a conglomerate zone above the Gangpur series may be taken as evidence of an uplift. Then followed the deposition of sands, clays, banded cherts and jaspers and clays, which constitute the Iron-ore series. Contemporaneous volcanism marked the close of the epoch in North Singhbhum, where basic lavas and pyroclastics were ejected, tongues of the magma penetrating the older sediments as sills and rarely as dykes. The whole of the era may be considered as one of geosynclinal sedimentation because of the extent and thickness of the beds. Then followed an orogenic period during which the sediments were piled up into mountains, accompanied by the intrusion of granite batholiths.

We can only speculate upon the extent of the Dharwarian geosyncline. A good deal of the area now occupied by granite was probably part of the geosyncline. It may have extended westwards and northwards to where similar lithological types of apparently the same age are known.

After this Archaean orogenesis, the Gangpur area has remained dry land except for an episode of fluviatile deposition during Gondwana times in the south-western corner.

CHAPTER VI.—THE GANGPUR SERIES—GONDITIC ROCKS.

GHORIAJOR STAGE.

The name 'Ghoriajor stage' is here proposed for the lowest portion of the Gangpur series comprising phyllites, mica schists and manganiferous rocks of the gondite facies.

Characteristic rock—Gondite.

The characteristic rocks of this stage are the gondites which occur along the central part of the anticlinorium, and extend from near Ghoriajor on the west to Gobira on the east.

In his exhaustive memoir on the manganese-ore deposits of India, Sir L. L. Fermor has named the more metamorphosed manganiferous rocks of Dharwar age, consisting mainly of quartz and manganese silicates, as gondite.[1] Though he proposed to restrict the use of the term gondite to the non-calcareous metamorphic rocks which show the association of quartz, spessartite and rhodonite, rocks in which other manganiferous silicates are also developed may be conveniently included under the term gondite series.

The gondite rocks are found over a large tract of country extending from north-eastern Bombay to Bihar and Orissa, a distance of about 700 miles. Sir Lewis Fermor has divided

Distribution in India.

the occurrences into three areas:[2] (1) the *western area* comprises the occurrences in Narukot State in the Bombay Presidency and Jhabua in Central India. This is separated by about 300 miles from the western end of the next area, (2) the *central area*. This includes the occurrences in the Chhindwara, Nagpur, Seoni, Bhandara and Balaghat districts of the Central Provinces. The width of the manganese-bearing series here varies between 8 and 15 miles. The easternmost occurrence is at Ukua (21° 58′ : 80° 32′) in the Balaghat district where it strikes approximately in an E.N.E. direction. This central area is about 110 miles long. The Dharwars here wedge in towards the east, being covered by the Vindhyans. The distance between Ukua in the Central area and (3) the *eastern area* in Gangpur State, represented by the exposures at Ghoriajor, is about 250 miles. But

[1] *Mem. Geol. Surv. Ind.*, XXXVII, pp. 306-307, (1909).
[2] *Rec. Geol. Surv. Ind.*, XLI, p. 20, (1911).

the westernmost extension of the accompanying Dharwars in Gang pur and the easternmost extension of those in Balaghat (Chilpighat series) are separated only by a distance of some 100 miles.

Two occurrences of manganese-ore, near Ratanpur and Gorakona in the Bilaspur district (the latter being some 55 miles north by west of Bilaspur), have been recorded by Sir L. L. Fermor,[1] but it is not definitely known whether they are associated with gonditic rocks.

It has already been shown (*see* page 18) that the rocks in the Lipripara area in which dolomitic marbles occur, are probably the western continuation of the Gangpur series and that they strike W.N.W.-E.S.E. The rocks of the Chilpi series in Balaghat have an E.N.E. strike. The area between the two is occupied by the Vindhyans and Gondwanas of the Raigarh State. It seems probable that the two Dharwar areas are connected underneath the younger rocks and that they can reasonably be taken as contemporaneous if not identical. As mentioned above, the distance separating the two is just over 100 miles. Sir L. L. Fermor has pointed out that there is a possibility of representatives of the Dharwars being present in the Archaeans of this intervening tract:

'Hence it is not unreasonable to expect that members of the gondite series, possibly with associated manganese-ores, may be found in the future in parts of this division, particularly in the Bilaspur and Drug districts, and Raigarh, and with less probability in the Raipur district; and also not improbably in the northern parts of the Sambalpur district in Bengal, immediately adjoining Gangpur on its southern boundary. In this connection it is interesting to draw attention to the discovery of manganese-ore at two localities in the Bilaspur district, although, as far as is at present known, they are of no economic value and occur in a very slightly metamorphosed facies of the Chilpi beds'.[2]

Typical gondite is exposed in a comparatively narrow belt of country in the Gangpur State. The westernmost occurrence is found to the south-west of Ghoriajor, about two miles north of Kinjirma. From here onwards, frequent exposures are noted in a north-east direction through Ghoriajor, Kendmal and Manomunda to some distance north-east of the last-named village.

Distribution in Gangpur.

The manganiferous zone in this group of exposures is the broadest in Gangpur State, being up to about 5 furlongs wide. There are nine or ten large sized quarries here besides a number of pits and trenches of various dimensions.

[1] *Rec. Geol. Surv. Ind.*, XL, pp. 334-335, (1910).
[2] *Op. cit.*, XLI, p. 20 (1911).

Further to the north east are occurrences near Ghantbur, Nakti, Raidih, Kharkamunda, Dhumagarha and Khorla.

The above are all in the extension of the Gangpur series in the area outside the anticlinorium.

Further on, similar occurrences have been noted at Dandjamira, Panchra, Jhirpani and Kohupani, in which the strike of the rocks veers round gradually from the north east to an easterly direction.

The above zone is apparently continued further east in Pandri sila, Ratakhand Jaidega and Gobira. In Gangpur, therefore, the occurrences are confined between east longitudes 84° 7′ and 84° 41′.

No representatives of the gondite series are known to the east of Gobira, though manganese ores, consisting of pyrolusite and psilomelane, have been found and worked at Tutuguta near Chaibasa in the Singhbhum district and near Jamda and Barabil at and near the political boundary between Singhbhum district and Keonjhar State. These occurrences, so far as known, seem to represent segregations of ore in the shales of the Iron-ore series, though in the latter places they form workable deposits of some size.

Origin.

After an extensive study of the gondite occurrences of India, Sir Lewis Fermor formulated a hypothesis of origin given on pages 364 and 365 of his memoir. The observations in this area go to support his conclusions, which are briefly given here:

'1. The rocks of the gondite series are the product of metamorphism of the less pure manganiferous sediments of Dharwar age, the metamorphism of these sediments having taken place towards the end of the Dharwar period.

2. A portion of the ores has been formed directly by the compression of the purest of the original manganese-oxide sediments.

3. Another portion of the ores has been formed by the subsequent alteration of the manganese-silicates produced by the above mentioned metamorphism.'

In a subsequent paper[1] Sir Lewis Fermor discusses the age of these ores in connection with the evidence obtained with regard to their mode of formation. During the twenty-five years that have elapsed since he published his main conclusions, no evidence has come forward to disprove any of them. On the other hand all observations during this period tend to confirm them.

The hard compact ore-lenses seem to be part of the original, nearly pure, sediments compressed by the post-Dharwar movements. The

[1] L. L. Fermor, On the Age and Continuation in Depth of the Manganese-ores of the Nagpur-Balaghat Area, Central Provinces. *Rec. Geol. Surv. Ind.*, XLI, pp. 1-11, (1911).

inclusions of dark ore in quartzites represent disseminations of ore in the original siliceous sediments. Only in the case of the lateritoid ore and the powdery crumbling ore which is distinctly seen to be formed around, and in the cracks of, the manganese silicates, can a superficial origin through decomposition be ascribed. But it seems probable that the ores formed secondarily by decomposition are also associated with the more compact and better ore formed by the partial alteration, at depth, of the manganese silicates.

A small part of the ore is due to the secondary deposition at and near the surface, by solutions, in cavities and joint planes. Such is the banded and botryoidal psilomelane sometimes found in the deposits, and also the comparatively thin sheets and films of ore found in shear and joint planes. This type of ore is however of practically no importance in the area.

The occurrences of gondite will be now taken up for description in some detail. The general lithology will be described here, the economic aspect of the deposits being deferred for treatment in Part II of this memoir.

Description of the occurrences.

Gobira.

A small outcrop of gonditic rocks is seen just to the west of the Gobira village (22° 19′ : 84° 44′). The extent of the exposure, including the associated lateritoid rocks, is about 250 yards by 120 yards. Rocks definitely referable to the gondite series are found over a length of some 50 yards and a width of 12 yards. They have a general E.—W. strike, and in a shallow quarry they are seen to pitch at 25° to 30° in an E. 10° S. direction.

The rocks include gondites associated with much quartz, some forming reefs of varying thickness. The gondite is fine-grained, dark grey to black and fairly soft, and crumbles readily under the hammer. On close examination with a pocket lens, a granular mass of yellow to brown garnet (spessartite) can be distinguished in places. In general, however, much of the garnet is altered to soft powdery ore.

Ratakhand (Jaldega).

About three miles in a N. by W. direction from the exposure at Gobira, are found two exposures of the same rock. The northern exposure is about 40 yards by 20 yards in extent and the southern one much smaller, and separated from the former by a distance of about 120 yards.

The two evidently form parallel zones, the intervening country being soil-covered. The rocks dip here towards N. 10° W. and can be traced in the direction of strike for only about 100 yards.

Pandrisila.

The main outcrop near Pandrisila (22° 20′ : 84° 43′) is a hill adjoining the north-western hamlet of the village. This shows much debris of gondite of the same nature as in the two places mentioned above, but small quantities of pink rhodonite can be seen in addition to quartz and spessartite (specimen No. 38/133).

Near the eastern end of the above hill is another outcrop oblique to it, also showing gondite, on its north-eastern flank. Parallel to the first hill, and about 300 yards north of it, is another zone showing quartz-rich gondite. The area between the two is occupied by mica-schists and carbonaceous phyllites. A few trenches mark the southern zone, where the rocks are harder and tougher than those found further east.

Kohupani, Jhirpani, Panchra.

For a distance of several miles to the west, no rocks of this nature are to be found. The hill-range of quartzite just north of Dalki (22° 19′ : 84° 31′) probably represents this stage and evidently continues into the similar quartzites forming a long hill between Samlaimunda (22° 18′ 30″ : 84° 30′) and Panchra (22° 17′ : 84° 22′). At the southern foot of this hill are found several outcrops of gondite, the easternmost being a short distance south of Kohupani (22° 19′ : 84° 27′). The gondite zone is here not more than some 30 yards wide. About a mile to the W.S.W. of this is Jhirpani, whence a continuous band can be seen up to a point south of Panchra. This exposure has been extensively pitted into for the purpose of winning the ore. The general dip here is very steep towards S.S.E.

Dandjamira.

Between Panchra and the hill W.S.W. of Kusamdega the country is covered by soil. At the eastern foot of the hill (1384) near the latter village, rocks of gonditic composition are found, but they are poor in manganese-bearing minerals. The band was followed up the hill but was lost after a short distance. A short distance to the south, however, the same rock is picked up again, just north-west of Dandjamira (22° 14′ : 84° 20′ 30″) having the same strike but evidently shifted more to the south-east. The manganiferous rocks here occupy a width of some 40-50 yards, the central portion showing some enrichment by ore. The strike is approximately N.E.-S.W. with

southeasterly dip of 50° to 70°. Though there are fine-grained dark quartzites in the hills just west of Mokundpur (22° 13′ : 84° 19′) these do not show any gondite. This seems to mark the westernmost extension of the gondite in the anticlinorium.

Dhumagarha-Raidih.

In the chapter dealing with the structure, it has been shown that the Gangpur series continues south-westwards beyond the anticlinorium. In this portion there are two bands of gondites exposed to the south-west of Bargaon, the eastern one extending from Dhumagarha (22° 8′ 30″ : 84° 16′ 30″) to Raidih (22° 6′ 30″ : 84° 15′ 30″) and the western one being found in the marginal portion of the granite boss one mile to the west of this. The eastern band is the broader, being over 150 yards wide at its maximum. The two bands are probably the result of folding of the rocks of the Ghoriajor stage. The western band shows two main exposures, the northern one near Khorla lying at the margin of the granite and the schists, and the southern apparently surrounded by granite. As the granite has given rise to much soil, the contacts are rarely seen, and no special effects have been noted because of such juxtaposition. Moreover the western band is much poorer in manganese minerals and ore than the eastern.

Khorla.

Nakti.

The rocks near Khorla show a general N.E.-S.W. trend and south-easterly dips. They are seen to continue towards the west in a series of comparatively small outcrops near Nakti, Ghantbur and Lahandabur. The strike is here nearly E.-W., (with southerly dip) but at the western end the rocks abruptly curve round and proceed in a south-westerly direction, leading to the Ghoriajor group of outcrops.

Ghoriajor-Manomunda.

In the Ghoriajor group, the more northerly occurrences, *i.e.*, those near Manomunda, show dips of about 60° or more, while the southern ones show 30°-45° but owing to frequent folding, variations are seen. The manganiferous rocks are frequently associated with quartz reefs and show intercalations of phyllites, mica-schists and quartzites. The manganiferous zone is about 1,000 yards wide, only a part of which exposes ores of high grade. The western half is generally of lateritoid character. The manganese-ore bands are the particularly rich portions of the manganiferous strata, and vary in thickness from a few inches to as much as ten feet. The bands

are however lenticular and pinch out at the ends, not only horizontally but also along their dip. The outcrops near Manomunda are about two to three miles north-east of Ghoriajor. The beds show moderate dips in general, but occasionally high dips and folded structures may also be seen. The manganese minerals are sometimes associated with quartzites. Sir Lewis Fermor has recorded the existence, at the time of his visit in December 1908, of a hillock of 50 ft. height situated 300 yards to the east (E. by S.) of the main workings, and showing banded gondite and ore. This hillock has since practically disappeared because of the quarrying operations.

Manomunda.

Around Ghoriajor there is a series of exposures now marked by pits of various sizes. Sir Lewis Fermor observed some seven exposures in 1908,[1] four in Kendmal and three in Ghoriajor. The most important exposure formed, at that time, a hill rising 70 to 80 ft. over the level of the plain to the east. This site is now marked by two large pits the 'Baragarha' and 'Semulgarha.' The total length of this exposure has been recorded as 720 ft. by Sir Lewis Fermor. The ore band, of 10 to 20 ft. thickness, sometimes showed an apparent thickness of 50 ft. owing to repeated doubling of the band as shown in his diagram[2] reproduced below.

Ghoriajor.

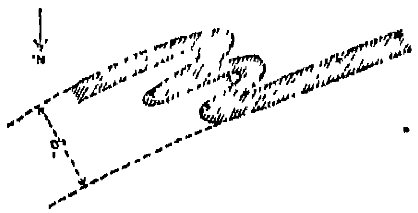

Fig. 2.—Sketch diagram of folding in manganese ore band in the Ghoriajor hill. (After Fermor).

Some two and a half furlongs to the E.N.E. of the main exposure, is another exposure called 'Shragor hill,' which has also been quarried into. About 400 yards to the south-west of the south-western end of the Ghoriajor main quarries is Prichard's hill, which seems to be due to another parallel band of gondite. To its north-east are also a few pits. In addition to the above, and in the strike of the manganiferous zone, there are several pits between Ghoriajor and

[1] *Rec. Geol. Surv. Ind.*, XLI, pp. 15-16, (1911).
[2] *Op. cit.*, p. 16.

Birjaberna villages. The last exposure is about half a mile S.S.W. of Birjaberna and about two miles north of Kinjirma.

MINERALOGY AND PETROLOGY OF THE GONDITES.

As remarked already, the Ghoriajor stage comprises phyllites, mica schists and quartzites with which, along a narrow zone, the gondites are intercalated. As the mica schists and phyllites are distributed throughout the whole country, they will be described in a separate section, and attention will be given to the gondites only. The gondites are generally very closely associated with highly quartzose rock or quartzite, which is often replaced by manganese minerals. Occasionally the quartzite is heavily impregnated with psilomelane or other manganese mineral and forms an ore.

Manganese minerals.

The chief manganese minerals found in the manganiferous rocks are spessartite, rhodonite, blanfordite and rhodochrosite and very small amounts of winchite and manganophyllite. Among the ore minerals, pyrolusite, psilomelane and braunite are common, while vredenburgite, hollandite and manganite are only rarely seen. As these minerals have been exhaustively described by Sir Lewis Fermor in his memoir, only the salient characteristics are touched upon here.

Spessartite.

The *spessartite* is an orange to brown coloured garnet, which, when well-developed, shows trapezohedral forms. It is however generally altered to ore. In thin sections the mineral is pale yellow or orange-coloured and shows replacement by powdery ore along the edges and cracks. Spessartite is universally present in all the exposures of the gondite in the Gangpur State, being always associated with quartz.

Rhodonite.

Rhodonite is present in only the Ghoriajor and Manomunda exposures and in the Pandrisila exposures. In the latter it is comparatively a minor constituent. It is very abundant in most of the occurrences of the former. Some pits west of Ghoriajor village and south of the main quarries expose bands and veins of almost pure rhodonite-rock, often several inches in thickness. The fresh mineral is rose-pink in colour and well cleaved and generally coarsely crystalline. It is very pale pink to almost colourless in thin sections, showing pyroxenic

cleavages with large extinction angles. This mineral also frequently alters to dark manganese-ore, the alteration starting along cleavage planes and extending to the interior. Some cases have been observed where another

Another pyroxene.

pyroxene is present in addition to rhodonite, in thin sections. It resembles rhodonite generally, but shows distinctive pleochroism, being colourless to pale orange in different positions in polarised light. In prismatic sections the extinction angles observed varied between 28° to 35° (slide 20180), the direction of extinction nearest the cleavage corresponding to the vibration direction of the fast ray (colourless). The individual grains show wavy extinction, the range of angle being about 7° or 8°. The maximum birefringence noted was somewhat higher than that of quartz (about 0·013). The larger crystals are diablastic, containing inclusions of quartz. It seems probable that this mineral may be a variety of rhodonite.

In the dump heaps of the Ghoriajor Manomunda group of quarries there occurs a small quantity of minute needles of a dark purple or red-brown colour. They are seen in some abundance only near about Mano-

Blanfordite.

munda, being, so far I am aware, absent in the more eastern exposures. Some of the sections examined (20172, 20180, 20181) show this mineral as lath-shaped individuals with well-developed longitudinal cleavage. As most of the thin sections examined were prepared from chips parallel to the foliation planes along which these laths lie, sections of the mineral transverse to the prism were only occasionally seen (20180). In these the cleavage appears to be distinctly pyroxenic. The mineral is highly pleochroic according to the following scheme :—

$\mathfrak{a}$—(elongation) bright carmine or rose-pink.
$\mathfrak{b}$—purplish blue or indigo.
$\mathfrak{c}$—bright greenish blue.

The maximum interference colours in sections of normal thickness are about the top of the second order. The interference figures obtained were not very satisfactory ; they however show the mineral to be optically negative. These characters would point to the mineral being *blanfordite* which has been described by Sir Lewis Fermor.[1]

[1] *Mem. Geol. Surv. Ind.*, XXXVII, pp. 125-126, (1909).

A silky fibrous mineral of lavender-blue colour having the characters of *winchite*[1] was found in the dumps of the Manomunda quarries. The mineral occurs as thin encrustations in cracks or cavities. The fibres are a few millimeters in length. In thin sections they show the following pleochroism :—

Winchite.

a light blue.
b- pale violet or lilac.
c- pink.

The extinction angle was observed to range up to a maximum of 36°.

A biotite resembling *manganophyllite* was also found at the same locality.

Rhodochrosite.

The manganese carbonate *rhodochrosite* has also been met with in the Ghoriajor area. The mineral is pale pink in colour and generally occurs in association with quartz and braunite. (41/648, 41/649.)

A specimen of rose-coloured quartz, the colour of which presumably is due to the presence of manganese, was collected near the Baragarha in Ghoriajor (41/650). In cases where the quartz contains microscopic or megascopic inclusions of manganese-ores, the quartz assumes a grey or black colour, according to the state of division of the particles and their abundance.

The ore minerals found here are braunite, psilomelane and pyrolusite.

Ore minerals.

Psilomelane is the most abundant mineral in the better quality ore of these deposits. It is found in the massive, botryoidal and concentric forms. It is fairly hard (H= 5·5 to 6) and is generally associated with braunite. *Braunite* is harder than psilomelane (H=6·5) and has a steel grey to black colour. It is the most abundant ore mineral next to psilomelane, and is often slightly magnetic.

Pyrolusite occurs in comparatively small quantities as a soft mass or powder. When crystallised, it has a metallic lustre. It is fairly common in the superficially altered portions of the gondite rocks. *Hollandite*, *vredenburgite* and *manganite* (41/648) were also identified among the minerals but, so far as known, they occur only in very small quantities.

[1] *Op. cit.*, XXXVII, p. 149, (1909).

Petrology.

The rocks of this group may be divided into gondites proper consisting essentially of quartz and spessartite, and other manganiferous rocks containing a variety of minerals. The former are prevalent in all the exposures, while the latter are mainly confined to the neighbourhood of Ghoriajor.

The typical gondites are generally granular mixtures of quartz and spessartite, the latter having been converted, to a larger or smaller extent, to ore. In many cases spessartite can with difficulty be identified with a magnifying lens, as it is coloured grey or black due to powdery ore occurring as inclusions or as alteration products. In thin sections the fresh garnet is orange or yellow coloured, and rarely shows (20174) anomalous birefringence.

The other group shows a greater range in colour, coarseness of crystallisation, and variety in composition. The minerals occurring are quartz, spessartite, rhodonite, blanfordite, winchite, rhodochrosite, biotite, chlorite and barite. A few typical varieties are described below:

Specimens 40/123 and 40/125 from the Ghoriajor area consist of rhodonite, spessartite and some ore derived from these, while 40/124 (20174) shows spessartite, rhodochrosite, rhodonite and diopsidic pyroxene. These and similar rocks sometimes contain a few grains of barite.

Blanfordite-bearing rocks seem to be restricted to the Manomunda exposures though occasionally seen around Ghoriajor. From the dumps of the Mohalgarha, specimens were collected (40/128 and 40/129) which showed abundant quartz, blanfordite, rhodonite and a little felspar. Garnet is rare in this type.

The thin section 20067 prepared from a rock collected near Pandrisila contains minute inclusions, in quartz, of a pink mineral, which seems to be piedmontite.

Rhombohedral manganese carbonate is fairly common in some of the rocks. Specimen 40/124 (20174) consists of abundant rhodochrosite, with subordinate diopsidic pyroxene, rhodonite, spessartite and a light yellow phlogopitic mica, while another (represented by the slice 20763) shows manganiferous carbonate, blanfordite, rhodonite, quartz, orthoclase, microcline, acid plagioclase and barite. 41/648 and 41/649 are mainly composed of carbonate associated with ore which is seemingly derived from the former, and some quartz.

CHAPTER VII—THE GANGPUR SERIES (*contd.*).- CARBONACEOUS PHYLLITES AND QUARTZITES.

There are two main horizons of carbonaceous phyllites, which grade into banded carbonaceous quartzites on the one hand and into slates on the other. Of these two horizons, one is older than the marbles and the other younger, and both are separated from them by a varying thickness of mica-schists. They are described together, since the lithological types are identical, except for the greater abundance of quartzites in the older zone.

Older Carbon phyllites.

This zone, to which the name *Kumarmunda stage* is suggested as a convenient name, is seen in small exposures right around the anticlinorium, and is an extremely useful zone in deciphering the structure. Its westernmost exposure is at Jarmal near Ghoriajor. Further east along this limb it is not distinctly seen, being probably too poor in carbonaceous material to be distinguishable from the associated phyllites. It should obviously pass through Telighana and Kutra forming a fold here. It is picked up near Dandjamira whence it takes an easterly course and is seen practically continuously, passing through Khatkurbahal, Jagadispur and Bamnipahar to near Kimang. At the latter place it is very sharply folded but the fold seems to pass into a shear zone or fault. Then it bends round towards the east again and passes through Siyaljor to Balimunda. Here again it is fold faulted and continues through Satra and thence westwards through Talsara and Raiboga to Tarkera. This zone is evidently folded back sharply, but exposures are rare hereabouts. A small patch is found close to the manganiferous rocks of Pandrisila. It forms the outer band of the Dublabera syncline, being seen as a continuous horse-shoe shaped outcrop passing through Purnapani, Hotpos and Kukuramunda. It seems to be pinched out to the west of the last-mentioned village.

At the eastern end of the anticlinorium this zone has been thrown into a series of remarkably close folds, which at the two places mentioned above, pass into sheared zones or faults. The formations younger than this do not form continuous outcrops in this portion, and are moreover covered over to a large extent by soil and

alluvium. Their behaviour therefore has been deduced from the configuration of this carbon-phyllite zone.

Younger Carbon phyllite.

The younger zone, which may be called the *Laingar stage*, is younger than the marbles. Its outcrops are much less continuous than those of the Kumarmunda stage. Its occurrence in the south-west is not definitely known. It is seen at Laingar, to the west of which it forms, due to folding, a double zone in the Katang syncline. It can be seen at intervals from Dahijora eastwards, the outcrops being often lateritised and not easily recognisable as carbon-phyllite in some places. It occurs again north of Bisra and can be seen passing through Ursu. It is repeatedly sharply folded near the Singhbhum border, a good anticlinal fold being seen near Khatang-tola and Kulagoja. From here onwards, isolated exposures are seen at Barilapta, Karimati and the hill ·1146 south of Sorda. It is bent back again through Katepur to Nawagaon and finally seems to pass north-eastwards to somewhere near the junction of Gangpur, Singhbhum and Ranchi. From here in a westerly direction a continuous series of outcrops can be followed up to near Raipura (Birmitrapur) and thence to Jambahal and Sadhumunda. It is again seen forming the elongated central band in the Dublabera syncline, where the exposure seems to represent a compressed double band which is pinched out towards the west.

It will be noticed from the map that this Laingar stage is in several places closely associated with epidiorite. This association is, in my opinion, indicative of the carbon-phyllites affording planes of weakness for the easy penetration of the traps which welled up along them by partial assimilation and replacement. This point is again referred to in the chapter dealing with the epidiorites.

Carbon-phyllites also occur in a few horizons in the Iron-ore series in the south-eastern part of the area. A broad exposure is seen extending for a few miles to the north-east and south-west of Ramjhori. To the south of this appears a long exposure which can be traced from near Jangidiri (22° 7′ 30″ : 85° 0′) through Kumbakera to Barmarain. This is probably continuous with the thin bed of similar rock associated with the epidiorite sill passing through Kichinda further west.

South of this, two fairly prominent beds of the same nature are found, all the three forming a noticeable bend, convex to the south, at about longitude 84° 50′.

Petrology.

For purposes of description, the carbonaceous rocks can be taken up under two heads, *viz.*, (1) carbonaceous slates, phyllites and schists and (2) carbonaceous banded quartzites.

The average specific gravity of 12 specimens is 2·57, the lowest and highest values being 2·42 and 2·68 respectively.

The phyllitic rocks are soft and vary in colour from ash-grey to dull coal-black. Some are so soft that they soil the fingers when handled and are powdered easily even by hand. All are fairly well-cleaved but only a few split up into thin slabs (40/33, 40/34, 40/52, 38/81, etc.). Others are splintery or 'woody' in structure (40/35). A few show knots owing to the development of chloritoid (37/969, 38/99) or of garnet. Others, which are generally better crystallised, show the presence of garnet and staurolite (38/100, 38/101).

Under the microscope they show varying degrees of crystallinity, some being slaty or phyllitic and others schistose. In the phyllitic rocks, the main mass is incipiently crystalline, only quartz and sericitic or chloritic matter being found. Occasionally however, partially altered crystalloblasts may be found. The quantity of carbonaceous matter is variable, but it is found intimately mixed with the ground-mass in the form of dust or clotted patches. Ferruginous material is also abundant in some, a few of the outcrops being highly lateritised.

The major portion of these rocks is of phyllitic character. In some, dirty-looking, partly clarified patches occur (20091, 20107). A thin section (20034) prepared from a specimen collected from the stream east of Raiboga shows bladed greenish crystals possessing faint pleochroism and low birefringence, with negative elongation and straight extinction. These seem to be minerals of the chloritoid group.

Another specimen collected from a thin band in a stream near Karanjkhol (22° 10′ : 83° 42′) shows megascopic flakes presumably of chloritoid, measuring up to 3 mm. across. In a thin section (21372) this mineral shows good cleavage and low birefringence.

Parts of the carbon-phyllite band east of Raiboga show evidences of regressive metamorphism. A specimen (38/100: 20035) from the stream about three-quarters of a mile east of Raiboga shows large crystalloblasts of biotite, garnet and staurolite. The last-named mineral especially is full of inclusions of carbonaceous matter. The groundmass contains mica, chlorite and a few laths of tourmaline. There is clear evidence in this occurrence of the rocks having been subjected to regressive metamorphic conditions.

Some of the occurrences near the contact with epidiorite sills show the development of abundant tiny tourmalines. A thin band of dark, hard, fine-grained rock, one mile south of Khatkurbahal, (40/54 : 20110) shows much microscopic tourmaline and a little magnetite. A similar, but more quartzitic, rock is exposed just north-west of Dhaurara (22° 16′ : 84° 30′), and another near Dahijora (20108 and 20112 respectively). Just south of the hill marked Δ1159, between the two last-named villages, is a band of carbonaceous phyllite (40/76: 20129) showing quartz and well-formed tourmaline laths (Plate 13, fig. 2). Both these minerals contain inclusions of dark dusty material. The latter mineral occurs as rounded, hexagonal, lozenge-shaped or long rectangular individuals, depending on the orientation in the thin section. In all these, the mineral is distinctly dichroic (colourless to pale orange) and negative uniaxial in optical character. The colour suggests that the tourmaline is rather poor in iron.

The carbonaceous rocks often show evidences of silicification. In some cases the silica occurs as veins, folded in with the rock. Some specimens, collected from an exposure at Taugrabahal (22° 14′ : 84° 21′) near Kusamdega, show the fine folding to which the rocks have been subjected (Plate 1, fig. 1). Some excellent examples of silicification are seen in the thin carbon-phyllite band occurring to the north of the epidiorite at Kichinda (22° 5′ 30″ : 84° 42′) and Jaraikela (22° 5′ : 84° 35′). At several places along this zone secondary quartz has replaced the carbonaceous phyllite to a considerable extent. A network of thin veinlets of quartz, enclosing partly filled-up cavities and sometimes resembling a 'box-work' pattern can be seen here (44/194, 44/195). The solutions which brought in the silica have obviously removed a good deal of carbonaceous matter, often leaving the rock porous and cavernous. This probably took place during the period of granitic intrusion at the close of the Dharwar times.

Banded carbonaceous quartzites.

The carbonaceous rocks pass frequently into thin bedded quartzites. The banding is made conspicuous because of differences in colour from pure white, through various shades of grey, to black. Sometimes the banding is extremely fine, the individual layers being almost of microscopic thinness. Those exhibit folding and faulting on a minute scale (37/906, 37/930, 38/80, *etc.*). Such rocks are particularly abundant in the upper portion of the Kumarmunda stage.

Carbon probably organic.

In their general characters, *i.e.*, the nature of quartz, fine banding and folding phenomena, these rocks show a remarkable resemblance to the banded haematite-jaspers of the Iron-ore series in South Singhbhum and the adjoining part of Orissa. The alternation of the materials which has produced this fine banding, is to be attributed to slow rhythmic deposition in moderately deep and still waters as in the case of the banded jaspers. The carbonaceous material in this case (as well as in the carbonaceous phyllites) was probably all of organic origin. The silica and carbonaceous clayey matter could have been deposited under regularly alternating and recurring conditions, probably controlled by seasonal variations. Our knowledge of the physico-chemical conditions producing rhythmic variations in naturally occurring sediments is still meagre and it is therefore not possible to outline the process of formation of these rocks satisfactorily. Seasonal variations in the nature and amount of the components, climatic and meteorological conditions, variations in the hydrogen-ion concentration, and the action of bacteria are some of the factors which may have been active in bringing about such rhythmic deposition.

Carbon content.

A few of the specimens of carbonaceous phyllite were used for the determination of the carbon content. The powdered specimen, mixed with potassium dichromate and lead chromate and contained in a porcelain boat, was placed in a hard glass tube which was ignited. Air was sent through the tube, freed from carbon dioxide and moisture by first passing it through tubes containing caustic potash, soda-lime and calcium chloride. The products of combustion of the contents of the porcelain boat were made to pass through a sulphuric acid bottle and tubes containing pumice soaked in copper sulphate solution, 'ascarite' and lastly calcium chloride. The tube of

'ascarite' which absorbed the carbon dioxide was weighed before and after the combustion, and the amount of carbon was determined therefrom.

Each specimen was ignited for two to three hours, till all the carbon was completely oxidised. The results of the determination are given below:-

Specimen No.	37/922,	44/169,	37/913,	37/961,	40/33,	44/192.
Carbon per cent.	1·64,	2·15,	2·36,	2·12,	2·50,	5·72.

Origin.

With regard to the origin of these rocks, Dr. Dunn[1] has postulated two hypotheses: either, that the carbon content is due to subaerial precipitation of carbon derived from the combustion of volcanic gases containing hydrocarbons and carbon monoxide: or, that the carbon was derived from the breakdown of fumarolic gases entrapped in the ashes and sediments.

Apparently in North Singhbhum no carbon phyllites are found which are not closely associated with epidiorite. But in the Gangpur area carbon-phyllites have been found without such association. The whole of the older carbon phyllites (except in one place) as well as some bands in the Iron-ore series in the south east are examples. It would appear that too much importance has been given to subaerial volcanic action in the formation of large thicknesses of phyllites, including the carbonaceous ones. Some of these have an ashy appearance, but such ashy looking specimens are composed mainly of siliceous material (quartz) with some ferruginous material. The carbon occurs in fuzzy clots and dust. The amount of sericitic and chloritic matter is practically always small so that the resemblance to volcanic 'ash' is only superficial.

There is again the rhythmic banding in parts of the deposits, which has been described above. This suggests deposition in alternate bands from colloidal solutions containing carbon derived from organic sources.

I am therefore inclined to favour the view that the carbon is organic in origin. It must be admitted that organisms began their existence soon after the cooling of the surface of the earth to a temperature which could permit organic life. For there must have elapsed a considerable period of time before the rich fauna of the Cambrian

[1] J. A. Dunn, Geology of North Singhbhum. *Mem. Geol. Surv. Ind.*, LIV, pp. 45-48, (1929).

with their chitinous and calcareous hard parts, suitable for preservation as fossils, were evolved and distributed all over the globe. As we go further back in time, the organisms must have been simpler in constitution. It appears highly probable that during Pre-Cambrian times there was a rich variety of primitive fauna and flora in existence. The view that the coals of later ages are to a large extent composed of a pervasive colloidal base of hydrocarbons through which the more resistant parts of the woody tissue and mineral matter are distributed, is now generally accepted[1]. Such hydrocarbon colloids could obviously have formed from all kinds of carbonaceous vegetable matter at all times during the sedimentary eras of the history of the earth. The importance of algae secreting calcareous structures in the building up of the limestone deposits of various ages is also now recognised. It seems therefore reasonable to conclude that the carbonaceous matter of algae and other primitive flora, perhaps mainly in colloidal form, may have contributed the carbonaceous material of the Pre-Cambrian shales and phyllites occurring not only in the area under consideration, but also in similar deposits in India (*e.g.*, the Himalayas) and elsewhere.

[1] C. S. Fox., The Natural History of Indian Coal. *Op. cit.*, LVII, pp. 9, 53, 226, 271, 273, (1931).

L. L. Fermor. On the relationship between the specific gravity and ash contents of the coals of Korea and Bokaro: Coals as colloid systems. *Rec. Geol. Surv. Ind.*, LX, pp. 315-350, (1928). Also two other papers dealing with Indian vitrains and durains. *Op. cit.*, LXII, pp. 180-228, (1929); LXIII, pp. 358-374, (1930).

CHAPTER VIII.—THE GANGPUR SERIES (*contd.*)— CALCITIC AND DOLOMITIC MARBLES.

The marble band, comprising a lower dolomitic member and an upper calcitic member, forms a distinctive and useful stratigraphical horizon, which may be called the *Birmitrapur stage*. As has already been mentioned, it is of great help in deciphering the structure, as it occurs all around the anticlinorium and south westwards up to the Ib river. In following the marble band, just as in the case of other stratigraphic units, from east to west, the strike is first seen to be E.-W. up to about the longitude of Rajgangpur, then N.E.-S.W. over the whole length up to near Kinjirma, and finally E.-W. in the exposures in the Sapai *nadi* near Bhasma.

Distribution.

Main southern limb.

This horizon can be picked up at its easternmost occurrence, which is close to Sukra. A few small exposures, mainly of dolomitic composition, are seen in the bed of a *nala* a little to the south-west of the village. Near San Bamua and in the *nala* west and north-west of it are several small exposures. A massive calcareous quartzite is seen on the bank of the Koel river just south of the village, while in the Katepur *jharia* an exposure of fine-grained, light grey, pyritiferous dolomite is found. The band then crosses the Koel river, being exposed in the river near Ursu. It can then be followed at a short distance to the south of and parallel to the river at Ursu, Khatangkudar, Bangurkela, Jagdah, Uparbahal and Banposh. At all these places, the exposure, which is generally between 250 to 300 yards broad, has been quarried to shallow depths particularly in the limestone portion. The unquarried portion of the outcrops, where not pitted, is seen to be marked by a lateritoid rock or soil cover. A large abandoned quarry worked for several years by the Tata Iron and Steel Co. mainly for dolomite, is seen at about one and a half miles north-east of Panposh railway station and east of Raghunathpali. The outcrop to the west of this quarry is found on the south-east bank of the Koel, which further on flows over the band completely

obscuring it. Further westward its strike coincides with the course of the Sankh for a short distance, the outcrop appearing on the south bank of the Sankh at Beldih and Bhalupatra, and again crossing over to the north of the river at Usra. At Beldih the outcrop is 250-270 yards wide and there is an abandoned quarry formerly worked by the Tata Iron and Steel Co. At Usra Messrs. B. P. Byramjee & Co. have been quarrying dolomite till very recently (1932). Limestone is seen here to the south of the dolomite at or very close to the river bank.

Western extension.

For a few miles to the west there are no exposures, but at Amghat the band is well seen and has been quarried by the Tata Iron and Steel Co. both for limestone and for dolomite during several years past. Continued westwards, almost continuous outcrops can be seen in a partly lateritised condition through Kisramal, Barajam and Lanjiberna. Here the band is some 400 yards wide. The hills near Dahijora and Gunatoli (west of Kiringsera) show the marbles especially on their southern flanks. The westernmost occurrence of this band is near Kendaimunda where it doubles on itself and can be traced back eastwards through Katang, Lakhotoli, Tilaimal to Barpali. The Katang and Barpali exposures were worked by the Bisra Stone Lime Co. and Jairam Valjee respectively. From considerations of structure it is clear that the scanty Barpali exposure is to be connected with the one at Kukarbhuka where it attains a width of over 600 yds. A lateritised country intervenes between these two places and, because of the wide distribution of the lateritic crust here, it is not possible to distinguish the marbles and separate them from the mica-schists which are also similarly lateritised. Thin-bedded, dark, flaggy limestones are exposed at Kukarbhuka over a width of some 1,900 feet. Some impure lateritised limestone patches show the continuation of these and connect them with the broad exposure near Purkapali. Here the width of the marbles is nearly a mile. The exceptional width of the outcrop at Purkapali seems to be due to a close fold which has brought about a doubling of the bed. It will be seen that this is accompanied by a similar fold in the conglomerate and quartzite band of the Mahabir Parbat. Two small exposures of calciphyre were also found near Birtola in the re-entrant of the conglomerate band of the Mahabir Parbat. The Niapara and Lakhopara patches are practically continuous with the Purkapali exposure. Further on the exposures become scarce. A small patch

is found in the Sapai *nadi* W. N. W. of Bijadih, and a series of exposures in the same stream is seen from near the intersection of the Ghoriajor road. From here onwards to south of Kinjirma the exposures are at close intervals; those near Bandubahal and Tilaimalti are in part rich in calc-silicates. Near Kinjirma limestones as well as dolomites are found, the latter occupying the whole width of the Sapai just south-west of the village.

At the bend of the Sapai south-west of Kinjirma, there are two bands of dolomite 50 yards and 80 yards wide respectively, separated by a band of quartzite which is in part slightly dolomitic and about 100 yards wide. These dip towards the S. S. E. at about 40°. Near the junction of the Gurli *nala* with the Sapai as well as near Bhalugarh there are small exposures of calciphyres. The last one is a short distance south-east of Kointra near the junction of the Ib and the Sapai.

Eastern end of anticlinorium.

We shall now follow this bed in the northern limb of the anticlinorium. The San Bamua and Sukra exposures are evidently continuous with those seen near Koilsuta and Chutia. At the latter place there is an exposure of white saccharoidal dolomite of some 250 ft. width. No calcareous rocks are seen to the west of Chutia, though possibly the lateritic patches conceal some. The bed then apparently turns eastwards and is seen exposed at Chitkidiri and near Ankurpali. The exposure, about a mile broad, of dolomitic marble in the Katepur *jharia* at this place, is attributed to an anticlinal fold which has practically doubled the width of the band.

Northern limb.

A small, partly lateritised, patch of the same rock is seen some distance north-east of Rampur, thus giving evidence of its close stratigraphic relationship with the carbonaceous phyllites. To the E. N. E. of this, further exposures are seen in the Deo river west of Khutgaon and near Kundra and Limra. The Kundra exposure is continuous for nearly a mile and a half, which again is due to repeated folding. An almost continuous stretch of dolomitic rocks can be seen along the Khatma *nala* from its junction with the Deo river, to near Banki—a distance of some 15 miles. The exposures in the Khatma *nala* are predominantly dolomitic. Limestone is seen along a band to the north of this, passing through Purnapani, Hathibari and Kokerma. The intervening area shows alluvium and soil, and the apparent discontinuity between the calcitic and dolomitic portions

seems to be the result of folding and partial denudation, or of the thinning out of the limestone.

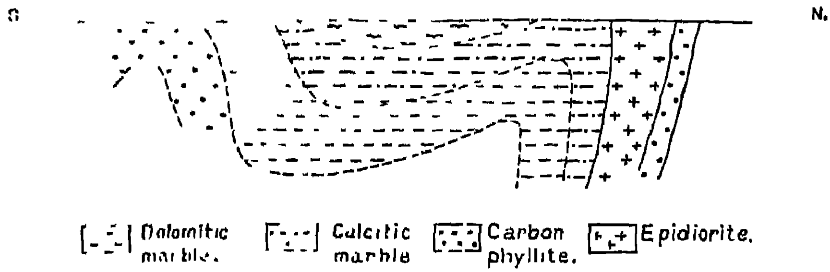

FIG. 3.—Sketch section from Bansjor through Bajnathpur (approximately along longitude 81° 51′ 30″).

This comparatively small fold seems to be non-existent in the western part of the exposure, *i.e.*, near Birmitrapur and further west, since there the whole band dips regularly northward at fairly high angles.

Throughout the eastern end of the anticlinorium, *viz.*, between San Bamua and Limra, the exposures of marbles and phyllites are very much obscured by soil cover. The older (inner) carbonaceous phyllite gives the main clue to the structure but the band of marbles exhibits just a sufficient number of exposures which afford confirmatory evidence.

The stream at Banki gives a few exposures of calciphyres, but west of this the band is seen only near Raiboga where it has a length of some three-fourths of a mile and a width of less than 600 feet.

In the subsidiary synclinal fold around Saromohan and Dublabera it is seen forming a horse-shoe shaped outcrop. The exposed width is much larger at the pitching eastern portion than in the two limbs. It is underlain as well as overlain by carbonaceous phyllites, *and dips towards the centre* underneath the central mass of carbonaceous phyllite. The southern limit of this fold can be followed for some distance but is obscured near Kukuramunda and is pinched out further west.

Dublabera syncline.

This zone reflects in a large measure the effect of folding on the width of its outcrop, every pitching portion of the fold showing a highly exaggerated extent of outcrop. Such is the case throughout the north-eastern and eastern edge of the anticlinorium and also in the subsidiary syncline around Saromohan.

Owing to the high mobility of the molecules of the carbonate under metamorphic conditions, a good deal of fine crumpling and

folding has been produced, which introduces confusion in the observations of dips. In the highly folded pitching portions especially, extremely variable and apparently contradictory observations are easily recorded. Much secondary silica has also been introduced into the limestones as veins which emphasize the minor structures to a remarkable extent. These structures are well brought out on the weathered surfaces because of the fact that very slight differences in composition are reflected in the colour and hardness of individual layers, which are at times a millimetre or less thick.

Phyllite zones.

In the main portion of the southern limb, the marble zone is separated by a belt of phyllites and mica-schists, which is 7,000-8,000 ft. wide, from the underlying carbonaceous phyllites. A much smaller thickness separates it from the overlying carbonaceous phyllites. But in the northern limb, the lower zone of phyllites is practically non-existent, while the upper is thin. In the Dublabera (Saromohan) syncline neither of the phyllite zones is present, the marbles being directly underlain and overlain by carbonaceous phyllites.

Strike directions.

In following the band of marbles from east to west, it is found that it has an E.-W. strike in practically the whole of the anticlinorium. From Amghat (Baipali) westwards the strike assumes a direction between E. N. E.-W. S. W. and N. E.- S. W. This is the case up to Kinjirma. Near Kointra it again becomes E.-W. Further to the west and south-west all the formations are extensively disturbed and displaced by granitic intrusives.

Lifripara exposures.

Some 18 miles to the W. N. W. of the last (Kointra) exposure mentioned above, however, dolomitic marbles are seen in the stream near Lifripara and Surgura. Here the strike has changed to W. N. W.- E. S. E., in conformity with that of the other members of the series. The dip is towards N. N. E. at 75° to 80° and sometimes vertical.

In the *nala* just north of Lifripara (22° 6′ 30″ : 83° 49′) the exposure extends for about 1,500 yards eastwards along the stream and 60-70 yards across, covering the whole width of the stream. After an interval, another exposure is found along the same strike and in the same stream half a mile further east where it resumes its original direction after executing a northerly bend. The western (Lifripara) exposure is about a mile long and the eastern (Surgura) exposure slightly less than half a mile long. The dolomite is, as

usual, highly folded and contorted and contains bands of somewhat varying degrees of purity. The impure bands are more common in the northern part of the exposure and contain quartz and tremolite.

The marbles disappear at either end of these exposures underneath the soil cover. They may probably continue on for some distance. It is not known whether the horizon is simply covered up or pinched out. No calcitic marbles are seen in this area.

All the exposures of the limestone and dolomite in Gangpur State have been examined by prospectors and the better outcrops have been worked at several places. At present quarrying is being done only at and near Birmitrapur. A short account of the quarries will be given in the economic section.

Thickness.

The width of the outcrop of the marble band shows variation from place to place. This is dependent not only on topography and local dip but also on the folding to which the band has been subjected. The effect of folding is however not prominent in the middle portion of the anticlinorium, which can therefore be taken for estimates of thickness.

The following are the approximate widths of the outcrop of the marble zone in different places:—

	Feet
Kointra (Bhasma)	1,000
Kinjirma	700
Bandubahal	500
Purkapali	5,400
Kukarbhuka	1,900
Amghat	2,200
Dahijora	700
Usra	1,600-2,000
Banposh	2,400
Jagdah	1,500
Birmitrapur	2,500-3,500

A few sections of the outcrops were measured by the writer on level ground, by pacing. At Birmitrapur the limestone portion of the band measures 750-800 ft. between the Patpahar (eastern hill) and Gurpahar (middle hill) and 1,000-1,050 feet between the Gurpahar and Manipahar (western hill). The dolomite portion was not measured owing to the irregularity of the ground.

In the Banposh outcrop the dolomite portion measures 1,600-1,650 ft. and the lateritised limestone portion probably 800-850 feet, the total being thus 2,400-2,500 feet. The average width of the band can be taken at between 2,000 to 2,500 feet with dips varying between 60° to 75° which gives a thickness of around 2,100 ft. Of this, between a half and two thirds is dolomite and the rest limestone.

Physical properties.

The limestone and dolomite can, to some extent, be distinguished by their appearance. The dolomite is generally white to light bluish grey in colour and fine-grained, whereas the limestone is darker bluish grey and generally coarse except where it contains appreciable quantities of argillaceous material. The dolomite is sometimes finely saccharoidal. The specific gravity of the limestone is around 2·7 and that of the dolomite around 2·8. When appreciable amounts of silicate minerals are present, higher values are obtained. A calc-gneiss (41/659) containing much tremolite and diopside gave a value of 2·90.

In weathered surfaces the dolomite generally develops a nearly white or light drab-coloured crust. The surface also appears much cracked and thin veins of quartz are not uncommon. Very fine crumpling and contortion are frequent (Plate 2, fig. 1). The limestone, on the other hand, shows more variation in appearance, comprising strata of greater range in composition and impurities than the dolomite. A limonite crust or brown discoloured outcrops are frequently seen. Frequent changes in the abundance of argillaceous, dolomitic and other impurities impart a good deal of variation in the appearance of the different portions. Owing to these impurities the limestone generally occupies the higher portion (*i.e.*, altitude) of the outcrop, though this may appear largely lateritic.

There are intercalated bands of an argillaceous nature amidst the limestone and dolomite. These are universally present. In the Dublabera exposure, there are bands of satiny chloritic phyllite (38/89: 20025) consisting of about equal amounts of chlorite and pale green biotite with a little iron-ore and tourmaline. Bands of chloritic and sericitic phyllites are abundant throughout the exposures in the Deo river from west of Khutgaon to north of Satra.

Petrography.

The calcareous and dolomitic rocks show all transitions from pure crystalline lime-stone and dolomite to calciphyres and tremolite-schists on the one hand and to calcareous phyllites and mica-schists on the other. Bands of calcareous mica-schists are common not only amidst the marble zone but also in the surrounding areas of the schists.

Typical bluish grey dolomites in the collection are represented by 37/898, 37/997, 38/79, 38/150, *etc.* Fine white saccharoidal dolomite is found just south of the eastern end of Mampahar at Birmitrapur and also in the Deo river near Satra, and at other places (37/935, 37/936, 37/998, *etc.*). Pink and light orange colours are also seen rarely (37/936, 37/999, 38,000).

Fine banding and crumpling are frequent features, in the dolomites much more than in limestones. A small exposure near Purkapali (Plate 1, fig. 2) shows this very well. Other exposures, for example near Sukra (Plate 2, fig. 1), Patrapali (in the Katepur *jharia*) Mijmiji and at several other places can be cited. Flaggy calcareous rock is seen near Kinjirma and Saromohan.

Dolomite.

Dolomite occasionally develops bands rich in tremolite bundles, as may be observed near Birmitrapur, Kinjirma and Dublabera (37/995, 38/90). The tremolite masses stand out prominently on weathered surfaces. Margarite flakes were seen in an exposure near Beldih (38/67).

Quartz, a magnesian mica and chlorite are also constituents of the rock (37/965, 37/938, 37/919, *etc.*). Megascopic pyrites is occasionally found (37/919, 37/923, 37/939, *etc.*) near Sau Banua, Birmitrapur and other places.

In the band just north of the Chutiapahar is exposed a saccharoidal white dolomite, which contains varying amounts of quartz as the only mineral in addition to dolomite (19923, 19924). This band is underlain by flaggy dolomite (37/965 : 19921) which shows much chlorite, biotite and quartz with subordinate dolomite.

In the Deo river near Satra and to its north, dolomites of all grades of purity are exposed. In the northern portions they grade into calcareous mica-schists (37/990 : 19932).

In the stream west of Banki dolomitic schist occurs containing a fair quantity of tremolite and a little phlogopite (38/30 : 19970). In the tremolite-schists, *e.g.*, near Purkapali, the larger cystals

of tremolite are diablastic with inclusions of dolomite or quartz (20133, 20131). Sometimes the mineral grades into a pale green actinolite owing to the presence of small quantities of iron (20116).

The tremolite is often accompanied by diopside (10/80, 10/81, *etc.*). Irregular crystals of diopside are seen in thin section 20157, containing a large number of inclusions of dolomite. The same section contains also flakes of a pale yellow mica which is presumably phlogopitic.

Dark carbonaceous dust-like inclusions are often found in the dolomite and tremolite (20116, 20121, *etc.*). Orthoclase and microcline (20089, 20121) and tourmaline (20211) are rare constituents. The tourmaline in the last case is associated with tremolite and shows orange-yellow to colourless dichroism, and is probably a magnesian variety, in contrast with the blue grey colours shown by the ordinary tourmaline in the mica-schists. A dolomitic marble near Beldih (38/68 : 20004) shows a few tabular crystals which are up to an inch in length. These show prismatic cleavage, negative elongation, straight extinction, medium relief (ϵ 1·555 ; ω 1·575) and medium birefringence. It seems therefore to be mizzonite (scapolite)

Limestone.

As remarked above, the limestone has better weathering qualities than the dolomite. The rock is often encrusted with residual lateritoid matter, the iron being contributed partly by pyrites, and partly perhaps by the siderite or ankerite molecules which may be present in the rock. In some places, for example near Kokerama, Hathibari and Purnapani, the greater part of the limestone outcrop is marked by a lateritic crust. It is generally found that the finer grained portions are more prone to lateritisation than the coarser, because they are rich in ferruginous and argillaceous impurities.

In his paper on the Raipura occurrence, Dr. E. Spencer has noted the following general characters of the limestone and dolomite :[1]

'(*a*) The dolomite, on the whole, contains less insoluble matter than the limestone, but this condition does not necessarily hold locally. The non-soluble portion of the dolomite is mainly fine-grained argillaceous or micaceous matter. In the limestone it may be argillaceous or sandy. The albitic limestone has usually a lower total alumina content than the argillaceous non-albitic limestone.

[1] *Mineral. Mag.* XX, p. 366, (1925).

(*b*) Traces of pyritic material occur disseminated through the dolomite and limestone, with a tendency to segregation in the argillaceous bands of the limestone.

(*c*) Carbonaceous matter occurs throughout the grey limestone. It is found inside the albite, quartz and tourmaline crystals, and is more abundant in the argillaceous bands than in the purer limestone. The dolomite is mostly free from carbonaceous matter.

(*d*) In the field, the change from dolomite with 21 per cent. MgO to limestone with less than 6 per cent. MgO takes place rapidly, and has evidently resulted from a change in the conditions of sedimentation.

The transition beds are mostly dolomitic and sandy. They vary from white at the base to dark grey at the top. The thickness of these beds is usually less than 50 feet.'

Kukarbhuka.

The small knoll of limestone at Kukarbhuka where some quarrying has been done, shows dark grey to nearly black, flaggy, fine-grained limestone. The carbonate shows fine dust-like inclusions, which may be partly carbonaceous and partly ferruginous. Some muscovite, light-coloured biotite and pyrite, and occasionally bluish pleochroic tourmaline, are also seen.

Most of the limestones that have been quarried in the area are grey coloured and show a small amount of impurities. The grey colour is probably to be attributed to very fine carbonaceous inclusions in the calcite grains.

Near the junction of the Sapai and the Ib there are exposures of tremolitic marbles in the former. They show diablastic tremolite (41/658 : 20773) with inclusions of rhombohedral carbonate or quartz, and small quantities of quartz, pale yellow phlogopitic mica and occasional pyrite grains.

Bhalugarh.

In the Sapai near Bhalugarh (21° 59′ : 84° 4′) a pale green, fine grained, schistose rock (41/660) is exposed. Under the microscope this shows quartz, microcline, a fair amount of 'spongy' tremolite, zoisite and a little calcite, sphene, muscovite and chlorite. Further to the north-east, at the confluence of the Sapai and the Gurli *nala*, a fairly coarse banded calc-gneiss is seen (41/661 : 20776) which consists of much calcite (or dolomite), tremolite and diopside with some quartz, microcline, biotite and sphene.

Birtola.

An exposure of what may be called calc-gneiss occurs in a low hillock a short distance west of Birtola. This rock (40/84 : 20137) is pale green in colour and contains diopside, quartz, microcline, tremolite, and a little chlo-

rite and sphene. A few grains of zoisite are also present. Another small exposure of similar rock was noticed about three fourths of a mile W. S. W. of the same village.

In the Sapai *nadi* west of Bandubahal is another occurrence of calc-gneiss (40/103 : 20155). This is a light bluish grey, fine-grained, compact rock containing quartz, microcline, orthoclase, rhombohedral carbonate and diopside. The last mentioned mineral is pale green in colour and diablastic with inclusions of quartz. Further north in the same stream a specimen was obtained (40/105, 20157) which shows diopside, carbonate, quartz and small amounts of phlogopite, pyrite and ilmenite altering to leucoxene. A calc marble from the Beldih quarry (22° 15′ : 84° 45′) showed a few micaceous flakes of a pale green mineral, which was identified as margarite.

Bandubahal.

Albite-bearing calc-marble.

Of particular interest is the occurrence of albite-bearing bands in the calc-marble in the Manipahar near Birmitrapur. The bands are found in the middle and upper portions of the limestones and are well seen in the exposures near the battery of lime kilns of the Bisra Stone Lime Co. One particular zone from which I collected specimens was found to have a length of over 1,000 feet along the strike and about 150 feet across, the albite being confined to alternate thin bands throughout this section. The albite stands out on the weathered surface as small lozenge-shaped crystals.

According to Dr. Spencer,[1]

'The albite occurs sparsely scattered through these zones, but in some places they are so crowded as to leave an abundant skeleton of crystals after solution of the limestone in acid. The crystals usually weather out on the bedding planes of the limestone slabs as tabular lozenge-shaped individuals ranging from one or two millimetres to a little over a centimetre in length.

The limestone associated with the albite is usually fairly free from argillaceous material, but some of the banded limestone contains albite crystals in the calcite material between the argillaceous layers. A few smaller, ill-defined crystals sometimes occur in the argillaceous substance itself.'

Specimens collected from one of the prominent bands (38/19 : 19959, and 38/75 : 20011) are composed of calcite and albite. The former contains only these two minerals, while the latter shows also some quartz and ferruginous matter probably derived from

[1] E. Spencer, *loc. cit.*, p. 367.

pyrite. A little mica is occasionally noticed. Dr. Spencer has also obtained zircon, sphene, garnet, rutile and tourmaline in small quantities from the insoluble residue of the albite-limestones after solution in acid.

The albite crystals are lozenge shaped and very flat parallel to *b* (010). Dr. Spencer, who has investigated them fully, states[1] that the best crystals are between 1 and 2 mm. long and show the faces *c* (001) and *p* (111) and occasionally *f* (130). They show twinning on the carlsbad and albite laws after the manner of 'roc tournée' twins. For further particulars his paper may be referred to.

Two analyses of the albite are given from Dr. Spencer's paper (*loc. cit.*, p. 371). They were made on clean selected material.

TABLE 3. *Analyses of Albite from Raipura (Birmitrapur).*

—	I.	II.
	Per cent.	Per cent.
SiO_2	66·95	67·10
Al_2O_3	19·72	19·95
Fe_2O_3	0·50	0·55
CaO	0·66	0·50
MgO	0·88	0·70
K_2O	0·52	0·60
Na_2O	9·95	10·30
Ignition loss	0·63	0·85
	99·81	100·55

I.—K. B. Sen, analyst.
II.—E. Spencer, analyst.

Origin.

The limestones and dolomites of the area show variations in the magnesia content, apart from the argillaceous, siliceous and other

[1] E. Spencer, *loc. cit.*, pp. 368-369.

impurities present in them. In general however a fair separation can be made between the dolomite strata and the limestone strata. The change from dolomite to limestone takes place rapidly. The transition beds of less than 50 ft. thickness are, according to Spencer, mostly dolomitic and sandy.

From the analytical results of several hundreds of samples taken at regular intervals in the Birmitrapur area, Dr. Spencer has come to the conclusion that the dolomite is on the whole purer than the limestone. This is also the general impression gained by me on examination of all the outcrops occurring in Gangpur State.

Regarding the conditions of deposition, Spencer states[1]:

'These facts suggest that the dolomite was formed under clear water conditions. Changes then set in which brought fine sandy sediment. Next followed conditions favourable to the deposition of calcium carbonate together with some organic matter and occasionally argillaceous and sandy material. It was during the last mentioned stage that the conditions appear to have been favourable to the formation of authigenic albite, quartz, etc.'

As will be seen from the data given in the economic section (p. 156-158) the limestone bands show a good deal of variation in the magnesia content. Daly has shown[2] from a study of the composition of some 700 analyses of limestones of various ages that the pre-Devonian limestones are invariably rich in magnesium and that there is a gradual decrease of that element in the limestones of later ages. The magnesian content is found to be very high in the rocks of pre Cambrian times. He attributes this to the pre-Cambrian seas being practically devoid of lime. This was brought about by the soft-bodied primitive marine fauna of the time decomposing quickly at death and producing ammonium carbonate, which, by reaction with the calcium salts brought in by the drainage of the land, would precipitate calcium carbonate and form ammonium chloride or sulphate. The pre-Cambrian fauna had not evolved to the stage at which they could build up calcareous skeletons, and there were at the same time no scavenging animals which would dispose of the remains of dead animals. The poverty of lime salts in the sea, brought about by the precipitation of calcium carbonate, helped the ammonium carbonate to react on the magnesian

Daly's views.

Chemical origin.

[1] E. Spencer, *loc. cit.*, p. 366.
[2] R. A. Daly, The Limeless Ocean of Pre-Cambrian Time, *Amer. Jour. Sc.*, XXIII, pp. 93-115, (1907).

salts and precipitate magnesium carbonate. In support of his arguments he cites the example of the Black Sea where there is no animal life below 100 fathoms and where the bottom muds are rich in powdery deposits of calcium carbonate,[1] and also the experiments of Murray and Irvine[2] regarding the precipitation of hydrous magnesium carbonate by the agency of a strongly alkaline carbonate.

Daly concludes[3] :

'We thus see how, in the nearly limeless sea-water of Pre-Cambrian time the proportion of precipitated magnesium carbonate would be high, even, possibly approaching the ratio in true dolomite. Indeed, it is quite possible that precipitates of pure basic carbonate of magnesium later changed to magnesite, were formed in those places in the sea-basin where the calcium salts were completely absent from the oceanic composition.'

He adds further[4] :

'Our hypothesis holds that the calcium carbonate of the dolomites and of the pure calcium-limestone was, for most of the Eozoic æon, introduced into the sea by rivers. Notwithstanding the slowness of the precipitation of magnesium carbonate at ordinary temperatures, some excess of magnesium salts in solution in the sea might easily permit the basic magnesium carbonate to be thrown down in very high proportion when compared with the precipitate of the other carbonate. What determined the actual composition of any one bed cannot be declared. Opposite the mouth of a large river we might expect beds of practically pure calcium carbonate. Far from the shores the chemical deposit would be more magnesian. Gradual changes in the rivers, in the marine currents, or in the configuration of the coast line, would cause alternations in the composition of the precipitate, the magnesian component *rising or falling according* to the highly variable circumstances.'

In addition to the original high content of precipitated magnesium carbonate, the dolomitisation of the limestones by the magnesium salts of the ocean is also envisaged.

In a later paper[5] Daly shows that calcium carbonate is mostly precipitated in the neritic zone and the shallower bathyal zone.

High magnesium content in Pre-Cambrian limestones.

Since, in pre-Cambrian times, the area of the landmass is supposed to have been much smaller than in later eras, the seas would have been shallower and would have afforded large areas for the deposition

[1] Guide des excursions, *VIIth Congres, Geol. Intern.*, No. 29, (1897).
[2] *Proc. Roy. Soc. Edin.*, XVII, p. 101 *et seq.*, (1890).
[3] Daly, *loc. cit.*, p. 107.
[4] Daly, *ibid.*, pp. 107-108.
[5] R. A. Daly, First calcareous fossils and the evolution of limestones. *Bull. Geol. Soc. Amer.*, XX, pp. 153-170, (1909).

of limestones. He calculates that, in pre-Huronian times, there was double the present area in the sea favourable to the deposition of limestone and eleven to twenty-eight times less possibility of river-borne calcium salts remaining in solution, and that in pre-Cambrian limestones the Ca : Mg ratio was 3·6 to 1·1 : 1, which is shown to be very close to the actual proportion of these elements in the rivers draining the pre-Cambrian terranes at the present day.

Since the Cambrian, the proportion of Ca : Mg in the limestones has steadily risen to the value of about 56 : 1 in the Cretaceous and 53 : 1 in the Tertiary.

A good deal of attention has been paid in recent years to the problem of origin of limestones and dolomites. It is now recognised that limestones form at fairly shallow depths. The absence of clays and sands in the general case is perhaps to be attributed to the low level of the coastal land which would allow very little suspended material to be carried into the sea. However, the presence of detrital materials (the heavy minerals of sedimentary petrologists) is also known in the limestones, so that these can be taken as having been carried into the area of formation of limestones by the streams. Since there were evidently few animals in the pre-Cambrian times with hard parts, fossil remains are practically unknown.

Influence of organisms.

In recent years the agency of algae[1] and bacteria has been recognised to be important in the formation of limestones. The algae deposit calcium carbonate in their stems and are found both under fresh-water and marine conditions. Marine calcareous algae have been found in coral limestones.[2] Clarke and Wheeler[3] have shown that their structures are highly magnesian. It seems therefore possible that the early Palaeozoic and pre-Cambrian limestones may have, at least to some appreciable extent, been formed by the agency of such algae[4], once we admit that a long period of time elapsed before the animals could evolve to the state of development of those which are met with abundantly in the Cambrian.

[1] E. J. Garwood, On the important part played by calcareous algae at certain geological horizons. *Geol. Mag.*, Decade V, Vol. X, pp. 440-446, 490-498, 545-553, (1913).

[2] M. A. Howe, The building of coral reefs. *Science, New Series*, Vol. 35, pp. 837-842, (1912).

[3] F. W. Clarke and W. C. Wheeler, The inorganic constituents of marine invertebrates. *U. S. G. S., Prof. pap.* 102, (1917).

[4] B. L. Miller, Limestones of Pennsylvania. *Penn. Geol. Surv., 4th Ser., Bull.*, M. 20, p. 48, (1934).

The precipitation of lime through the agency of bacteria[1] is also known through the work of Drew and others. Drew's view is, however, partly contested by R. M. Field,[2] who thinks that the limestones are not formed in the open ocean in the manner outlined by the former. In the Bahamas there are many localities where urea bacteria precipitate calcium carbonate under certain conditions. Sulphate reducing bacteria as well as cellulose-destroying ones are also present. The last are held to be responsible for the decomposition of the abundant organic matter in the swamps and also for aiding in the precipitation of calcium carbonate.

Dolomite.

With regard to dolomite, the study of the pre-Cambrian strata exposed in the forty ninth parallel in the Rocky Mountain geosyncline region, led Daly[3] to conclude:

'The constituent particles are either idiomorphic and roughly rhombohedral, or anhedral and faintly interlocking. The former are everywhere of nearly uniform average diameter, ranging from 0·01 millimeter to 0·03 millimeter with an average of about 0·02 millimeter. The anhedral grains range from 0·005 millimeter to 0·03 millimeter averaging about 0·015 millimeter.'

The same uniform grain prevails in the Archaean dolomites of Idaho and in the Cambrian limestones of Montana. The average grain size is very close to that of chemically precipitated calcite and dolomite crystals, for example in the Norwegian dolomite and in the precipitates of calcite in the cavities of the Funafuti coral limestone. There have been other advocates of the chemical precipitation theory, as well as of organic and clastic modes of origin. Perhaps the most widely held view at the present day is that dolomite was formed by the replacement of limestone mainly by the action of the magnesian salts of the sea-water.[4] Excellent summaries of the various hypotheses of origin proposed by different authors have been given by F. M. Van Tuyl[5] and F. W. Clarke.[6]

[1] G. H. Drew, On the precipitation of calcium carbonate in the sea by marine bacteria. *Carnegie Inst. Washington, Publ.*, 182, pp. 7-45, (1914).
K. F. Kellerman and N. R. Smith, Bacterial precipitation of calcium carbonate. *Jour. Wash. Acad. Sc.*, IV, pp. 400-402, (1914).

[2] R. M. Field *et al*, Geology of the Bahamas. *Bull. Geol. Soc. Amer.*, XLII, pp. 759-784, (1931).

[3] *Bull. Geol. Soc. Amer.*, XX, p. 168, (1909).

[4] The Atoll of Funafuti, (Royal Society, London), (1904). J. W. Judd's report on chemical examination, pp. 362-382.

[5] F. M. Van Tuyl, The origin of dolomite. *Iowa Geol. Surv.*, XXV, pp. 257-421, (1916). Conclusion, pp. 397-406.

[6] F. W. Clarke, Data of Geochemistry. *U. S. G. S., Bull.*, 770, pp. 565-580, conclusion on p. 578.

In the present case the only organisms which could have taken part in the formation of the rock are primitive ones like algæ and bacteria. The processes which can be conceded as having taken place are:

1. Direct precipitation of mixed carbonate by chemical or organic agencies, or both.
2. Enrichment of magnesian carbonates by the leaching away of some of the calcium carbonate.
3. Replacement of calcium carbonate by the dolomite, the magnesium being supplied by the sea-waters.

The last is considered by Van Tuyl and Clarke to be the most important in the stratified dolomites. Magnesium salts are contained in more abundance than calcium salts in sea-water, and the sulphate of magnesium seems to be the more active agent in this replacement. The factors which help in the replacement are the presence of aragonite in the original limestone, fineness of grain, porosity and warm temperature.

In the pre-Cambrian metamorphosed limestones like those under consideration, it is practically impossible to find evidences of all the processes which might have contributed to their formation. If the conclusions of Van Tuyl and Clarke are generally applicable, then the dolomitic beds under consideration may be supposed to have been originally laid down as limestones with an appreciable magnesian content, and later on, as deposition proceeded, gradually enriched to true dolomitic composition. The sandy transition beds mark the limit of the dolomites. The formations which followed later were limestones (somewhat magnesian in certain bands) which were probably deposited at quite shallow depths, as evidenced by comparative frequency and richness of siliceous, argillaceous and organic matter, but which have not been dolomitised to any extent.

Metamorphism.

Since their deposition, the dolomite and limestone beds have been subjected to metamorphic conditions which brought about their conversion to crystalline marbles. The associated argillaceous materials have become phyllites and chloritic mica-schists. The marbles have been completely recrystallised, often to a coarse grain, and been folded, crushed and sheared. Subsequent veins of calcite and quartz have been introduced. Silicate minerals like

diopside, tremolite and actinolite, phlogopite or magnesian biotite, tourmaline, albite and margarite have been produced. Dr. Spencer mentions the presence of garnet in these, but as these seem to be present in microscopic quantities only, and as I have not come across any garnet definitely ascribable to metamorphism of the limestones, the mineral is probably of detrital origin and contained in the original clastic material which was deposited with the carbonates. But, since garnet is abundantly present in the mica-schists of the region, its production in the marbles by metamorphism is quite possible. So far, however, only detrital garnet has been met with.

Much of the mineral assemblage of the marbles is characteristic of the epi-zone of Grubenmann. But the presence of tremolite in all the outcrops and of diopside in the western and south-western parts, definitely indicates the conditions of a deeper zone. From other evidence, which will be discussed in connection with the mica-schist, it is clear that the rocks of this area have undergone regressive metamorphism and that epi-zone characters have to some extent obscured the meso-zone ones.

Both the limestone and dolomite beds show the development of silicate minerals. It is now well known that calcite[1] dissociates at atmospheric pressure at 900°C. and that a weight of rock equivalent to forty metres thickness prevents its dissociation up to 1,100°C.[2]

The dissociation temperature of dolomite has not been definitely established, but it is lower than that of calcite. This is recognised in practice in lime-burning, where magnesian limestones are dead-burnt at lower temperatures than pure or high-calcium limestones. It is also generally conceded that the presence of moisture and of impurities such as silica, alumina, *etc.*, brings down the temperature of dissociation and aids in reconstituting the rock into a marble with silicate minerals. Eskola states[3] that the lime-silicates in marbles are good indicators of metamorphic conditions, the lower temperature zones being characterised by quartz and some other

[1] J. Johnstone, Thermal dissociation of calcium carbonate. *Jour. Amer. Chem. Soc.*, XXXII, pp. 938-946, (1910).
F. H. Smyth and L. H. Adams, The system, calcium oxide—carbon dioxide. *Jour. Amer. Chem. Soc.*, XLV, pp. 1167-1184, (1923).

[2] N. L. Bowen, Geologic Thermometry (in 'the Laboratory Investigation of Ores' edited by E. E. Fairbanks, New York, 1928), pp. 189-190.

[3] P. Eskola, The mineral facies of rocks. *Norsk. Geol. Tidsskrift*, VI, p. 165, (1920).

epi-zone minerals, while the higher temperatures produce tremolite, diopside, garnet, wollastonite, *etc.* He has distinguished four paragenetic types belonging to successively higher temperature zones in Finland[1]:

1. Quartz-limestone in which quartz is co-existent with dolomite.
2. Tremolite-limestone. Tremolite is usually present; quartz occurs in calcite rock but is not co-existent with dolomite.
3. Diopside-limestone. Diopside is usually present; quartz occurs together with calcite but not with dolomite.
4. Wollastonite-limestone. Wollastonite is present provided the rock contains silica in excess of the amount needed to form the magnesium-bearing silicates. Quartz and calcite do not occur in direct contact with each other, but wollastonite may abut against quartz or against calcite.

According to Eskola, the tremolite may occur partly in the 'greenschist' facies and partly in the 'amphibolite' facies, but diopside occurs only in the latter.

Though these facts are widely recognised, no quantitative data are available about the conditions of formation of the lime silicate minerals. V. M. Goldschmidt[2] has calculated a temperature range of 500°C. to 800°C. for variation in pressure between 1,000 and 2,000 atmospheres as the limit within which quartz and calcite can co-exist in rocks. But Bowen[3] states that the temperatures corresponding to the above pressures should be somewhat lower than those calculated by Goldschmidt. So far as I am aware, no wollastonite-bearing marbles occur in the area under consideration. It appears therefore that the temperatures necessary for the formation of that mineral were not attained under the high pressures obtaining in the strata during metamorphism.

With regard to the albite in the albite-bearing limestone, Spencer[4] comes to the conclusion that it is authigenic, and states in support:

'The idiomorphic form and other characters of these albite crystals preclude a clastic origin. A metamorphic origin would also involve many difficulties, among

[1] P. Eskola, On contact phenomena between gneisses and limestone in Western Massachusetts. *Jour. Geol.*, XXX, p. 283, (1922).

[2] V. M. Goldscmidt, Die Gesetze der Gesteinsmetamorphose. *Viden. Selskr. Skr., Math-Naturw. Kl.*, No. 22, p. 12, (1912).

[3] N. L. Bowen, *loc. cit.*, p. 191.

[4] E. Spencer, *loc. cit.*, pp. 372-373.

which are (*a*) the arrangement of crystals in zones parallel to the bedding, (*b*) the absence of other minerals of purely metamorphic origin, (*c*) the source of the sodium, and (*d*) the relative purity of the albite, especially freedom from lime.

The limestone has certainly suffered metamorphism and in places the folding has been intense. This metamorphism, however, does not appear to have resulted in any mineralogical rearrangement, and the albite present in the folded areas has shared in the metamorphism, having become strained and sometimes shattered, without evidence of reconstitution. The fractures are often clean and sharp, the crystals having obviously been formed prior to this movement...... . There are no signs of igneous activity in the neighbourhood. It appears highly probable, therefore, that this albite is authigenic, in which case a similar origin for the idiomorphic quartz crystals, the pyrites, the rutile, most of the mica, and probably most of the tourmaline might also be possible .... The view of an authigenic origin for these minerals is strengthened by a comparison with other recorded occurrences of felspar in sedimentary limestones and dolomites, many of which have been definitely shown to be authigenic.'

The term 'authigenic' implies that the mineral was formed under ordinary conditions and grown *in situ*, contemporaneous with or soon after the deposition of the strata. It is admitted however that the rocks have been folded and metamorphosed. In some of the parallel bands in the neighbourhood there is tremolite in the marble bands. The albite is always associated with fairly coarse crystalline calcite which is evidence of metamorphism. The age of the series is considered by Spencer and by all others who have described the area till now as Cuddapah (or Vindhyan), but the present writer has adduced evidence to show that it is definitely Dharwar. Again, the large size of the albite crystals (up to 1 cm. long) is not in favour of a purely authigenic origin. Though it may be admitted that crystals of felspar occur in unmetamorphosed limestones, their usual size is between 0·01 mm. to 0·08 mm.

The fact that the albite crystals are broken by later movements does not preclude their having been formed under metamorphic conditions. In any case, they could have formed during the early stages of metamorphism. We have in this area abundant evidence of more than one period of folding, and a period of regressive metamorphism, so that when the folding was intense, the fractures would have developed without necessarily reconstituting the rock. As J. T. Singewald Jr. and C. Milton[1] point out: -

'The Bengal limestone has undergone metamorphism and close folding, and the evidence adduced by Spencer does not preclude the formation of the felspar at an early stage of this metamorphism.'

[1] J. T. Singewald Jr. and Charles Milton, Authigenic feldspar in limestone at Glen Falls, New York. *Bull. Geol. Soc. Amer.*, XL, pp. 466-467, (1929).

The absence of any reconstitution of the rock is not of special importance, since under the low grade of metamorphism postulated here, such a change may not occur.

Dr. Spencer, with whom I have recently discussed this question, points out that the size of the albite crystals is not a reliable criterion, that there are no occurrences, to his knowledge, of limestone or dolomite containing albite or other felspar of proved metamorphic origin, and that there is no tremolite or other metamorphic mineral in the albite-bearing zones. The differences between our points of view largely disappear if it is made clear that the conditions of metamorphism envisaged are those of Eskola's temperature zone 1, referred to on a previous page. Whether the term 'authigenic' can be applied to minerals formed under those conditions will then be perhaps a question of opinion.

CHAPTER IX.- THE GANGPUR SERIES (*concld.*).

MICA-SCHISTS AND PHYLLITES.

By far the most abundant and widespread rocks of the region are mica-schists and phyllites. They form parts of the geological succession at all horizons, and are para-schists representing metamorphosed argillaceous material. Where abundantly intruded by granites and partly assimilated by them, they form composite gneisses and felspathic schists.

There is a large variation in the appearance and characters of those rocks. To the east of the Gangpur anticlinorium they are phyllitic in character, being of a fairly low grade of metamorphism. In the greater part of the anticlinorium and in the area between it and the granite batholith of Ranchi, they are highly metamorphosed to crystalline schists bearing garnet and staurolite. The crystallinity as well as the mineral composition is very variable, and moreover even the highly metamorphosed rocks simulate the phyllites as they have generally been subjected to retrograde metamorphic conditions.

In the Gangpur series there are, strictly speaking, no true phyllites. For even in the rocks which contain nothing but quartz, mica and chlorite, structures[1] are frequently seen which show evidence of the rocks having been subjected to metamorphism of a higher grade than is apparent at first sight. The granitic intrusives have affected the coarseness of crystallisation as well as, to some extent, the mineral composition. The repeated tectonic disturbances have left their impress on the rocks, as for instance in the rotation of the porphyroblasts and in the partial reversion of minerals to their representatives of a lower grade of metamorphism.

For the sake of convenience the general characters of all the phyllites and mica-schists of both the Gangpur series and the Iron-ore series are given here, and references will be made to these, where necessary, in the description of the Iron-ore series.

Phyllites.

The rocks may be divided into phyllites or sericite-schists and mica-schists. The phyllites are generally grey in colour ranging

[1] E. B. Knopf, Retrogressive metamorphism and phyllonitization. *Amer. Jour. Sc.*, XXI, p. 14, (1931).

from silvery white to lead grey and brownish [illegible]. They always show very fine foliation which sometimes coincides with the original bedding of the sediment. Adopting the recent continental usage, these may be called phyllonites. These rocks are particularly abundant in the south-eastern part of the area but within the anticlinorium itself are several occurrences which can be included here for purposes of description. The [illegible] when fine-grained (37/950, 40/[illegible], *etc.*) [illegible] underlying the crushed conglomerate north of B[illegible]. Here the rock clearly shows strain slip cleavage in addition to lamination which represents the original layers of deposition.

In several occurrences very fine puckerings and crumblings are noticed, especially when specimens are broken across the foliation (40/141, 43/171, 41/115, *etc.*). Lead grey to dark crumbled phyllites occur in association with the conglomeratic rocks at Sibrajpur. Similar but light pink or purplish rocks are seen in the hill section east of Karamdih.

The specific gravity of the phyllites, including the chloritic ones, has the average value of 2·78, the highest being [illegible] and the lowest 2·754.

In general, the phyllitic (or phyllonitic) rocks show a large amount of fine-grained sericitic and chloritic material in association with quartz. Sometimes thin quartz veins traverse them. There are several cases in which such rocks show the occasional presence of porphyroblasts of biotite or garnet, which have been rotated and altered to a large extent.

These grade sometimes into spotted schists or *knoten schiefer*, the knots being minute garnets or clots or aggregates of biotite and chlorite. These represent individualised crystalline minerals which have built up comparatively large crystalloblasts by migration or transference of material during metamorphism.

Mica-schists.

There is every gradation from rocks which are phyllites to those which are mica-schists, in the varying coarseness of the component individual minerals. There are muscovite-schists and biotite-schists, and others which contain both the micas. In a good many places garnet and staurolite have been developed, and in these occurrences, crystalloblasts of biotite and chlorite are generally to be seen. A varying amount of quartz is always present. In some, carbonaceous

or calcareous material is present, so that the variety of appearances presented by specimens from the different exposures of the area is great.

Variations in colour, texture and structure are also frequently seen. The usual colours are grey, buff, and brown. Gneissose and schistose structures, with slaty, splintery or massive character, are met with.

The average specific gravity of hand-specimens from different localities was found to be 2·785, the maximum recorded being 2·896.

The minerals present have been mentioned above. In addition to the major or essential minerals, there are also those occurring in small quantity, as magnetite, ilmenite, sphene, apatite and tourmaline.

The *biotite* is yellow-green generally, and bronze or brown occasionally. When occurring as crystalloblasts its outline is roughly rectangular or square (37/962, 38/37). The edges at the ends of the cleavage traces have frequently a frayed-out appearance. It is prone to chloritisation, and indeed in some cases there is clear evidence that the penninite crystalloblasts represent altered biotite. Thin sections 20165 and 20169 are interesting in that they show extremely fine filiform growths projecting from the biotite into the neighbouring quartz. These growths being very thin and occurring enclosed in quartz have not been definitely identified, since, in determining the birefringence and the extinction angles, the interference colour of the enclosing mineral proves to be an obstacle; but there are indications that some of them at least are amphiboles. This is probably a synantetic phenomenon.

The biotite porphyroblasts are frequently studded with inclusions around which pleochroic haloes have developed (19975, 20088, 20781, 20788, *etc.*). In some cases sphene can be definitely identified as the inclusion giving rise to these radioactive haloes. Zircon may also be present.

The *garnet* is the red variety, apparently the common almandite. In thin sections it is pale pink and usually presents excellent crystal outlines of dodecahedral sections. Some however show irregular edges, where, and in the abundant cracks generally present, they have altered to limonitic material. The crystalloblasts practically always show drawn out, thin, spindle-like inclusions of quartz, which may be taken as having been formed during metamorphism,

The direction of elongation of these should obviously represent the direction perpendicular to the pressure developed during diastrophism, *i.e.*, parallel to the original planes of foliation. It is generally observed that the inclusions in garnets in the same section have a more or less similar orientation, though this may be quite different from the foliation planes found in the minerals of the groundmass. The garnetiferous schists are, as a rule, rich in biotite and comparatively poor in muscovite. Besides the above-mentioned quartz streaks, there are needle-like black minerals, grains of iron ore and flakes of chlorite, as inclusions in the garnet.

The *chlorite* porphyroblasts have the characters of *pennine* (20088, 20142, 20185, *etc.*). They show fine cleavage traces and distinct pleochroism (from light yellowish green to dark green). The mineral also occurs in the groundmass of the mica-schists sparingly. There are also gradations from mica-schists poor in chlorite on the one hand to chlorite-schists on the other.

The mineral sometimes shows very fine acicular inclusions of magnetite or rutile, arranged parallel to three directions at 120° to each other (20784). Pleochroic haloes are also present in many cases (19975, 20088, 20198, *etc.*), the inclusions around which these appear being similar in character to those found in biotite.

Staurolite[1] is fairly abundant in certain definite zones, *e.g.*, in the central part of the anticlinorium, around Lasá and Talsara, to the north of it at Potob and its neighbourhood, in the strip of schists to the west and north-west of the granite boss of Ekma, alongside the northern border of the conspicuous basic sill which extends from Gailo to Rabga, and in a few other small occurrences. Excellent crystals have been obtained from a few places alongside the above mentioned basic sill, especially near Kichinda, Lodabasa, Jaraikela and Chuliam. These show both the X-shaped twins with (232) as the twinning plane, and the *plus* (+) shaped twins with (032) as the twinning plane. Trillings have also been collected from near Rengalbera (22° 7′ : 84° 41′) north of Kichinda. The faces found in these crystals are *m* (110), *c* (001), *b* (010) and *r* (101).

In thin sections they show the characteristic pleochroism. They are typically 'sieve'-textured, owing to large numbers of drawn-out inclusions of quartz. Biotite flakes are also sometimes found. The staurolite and garnet are practically always closely associated, sometimes the one being partially moulded around the other.

[1] M. S. Krishnan, The occurrence and distribution of Staurolite in Gangpur State, *Quart. Journ. Geol. Min. Met. Soc. Ind.*, V, pp. 67-74, (1933).

The occurrences at Lasé and Potob are apparently not connected with igneous intrusives, and are probably due to high compression and temperature developed in certain definite zones parallel to the schistosity. With regard to the strip of schists to the west and south-west of Ekma, it will be noticed that it is bounded on both sides by granitic rocks, which are obviously connected underneath it. The presence of granite may therefore have had some effect on the formation of the mineral. Again, the zone bordering the Gailo-Rabga basic sill is on the side towards which the sill dips. The formation of the abundant and excellent crystals here may be attributed to the metamorphic effect of the sill on the schists just overlying it.

Tourmaline is present in the mica-schists as small laths and needles, which are sometimes large enough to be readily seen in hand-specimens. In polarised light it is generally light greenish grey to dark greenish grey or brown. Sometimes it is pinkish for light vibrating in one direction and dark greenish brown in another direction perpendicular to the first (20227).

It is so frequently present that it may be regarded as a common constituent. There is some evidence that the granites and pegmatites of the area have been responsible for the introduction of tourmaline in the schists in their neighbourhood. The granitic rocks themselves are rich in this mineral, and in several exposures of schists near the contact, an enrichment in tourmaline can be clearly seen.

Its wide distribution in para-schists may indicate that—

(1) the necessary boron content was present in the original sediment, or

(2) the boron was introduced by granitic intrusives exposed in, or underlying, the area.

The presence of boron in sedimentary rocks in appreciable quantities has been established by the recent work of V. M. Goldschmidt and C. Peters[1], who found that the following average quantities are present: —

	Per cent. B_2O_3.
Marine clay sediments	0·1
Marine sedimentary iron ores	0·05—0·005
Lake deposits and bog ores	0·001 and less
Bauxite and Kaolin	0·001 and less
Ash of marine plants	1·0—0·05
Coal ash	1·0—0·1

[1] V. M. Goldschmidt and C. Peters, Zur Geochemie des Bors., *Nachr. Ges. Wiss. Göttingen*, pp. 402-407, 528-545, (1932).

They have examined the results obtained for a large number of materials and conclude that igneous rocks and their weathering products contain very small quantities (0·005 per cent. or less of B_2O_3) but that marine sediments, especially the older ones, average about 0·1 per cent. This high content is attributed by them to the sea water in which Dieulafait found about 0·2 gm. of boron per cubic metre. This may have been derived from the original atmosphere or from volcanic emanations. The large amount of sea-water included in the sediments during deposition can evidently account for the boron content.

Source of boron.

Thus the argillaceous marine sediments contain enough boric oxide to form an appreciable quantity of tiny crystals of tourmaline on metamorphism. It is therefore clear that in most cases the tourmaline in the mica-schists is derived from the original boron content of the sediments. Local enrichment by contribution from the neighbouring granite masses has also demonstrably taken place.

Apatite is a sparsely distributed accessory (20198, 20784, 20830, *etc.*). Its presence was noted in several cases, but it is more abundant in some of the felspathic schists which bear evidence of the influence of granite.

The mica-schists and phyllites grade into felspathic schists and gneisses, injection-gneisses and hybrids depending on their proximity to, and interaction with, the granite. A few of the garnetiferous rocks are described below.

Garnetiferous gneisses and schists.

Near Buchkupara (22° 8′ : 84° 35′) and north of Chuliam, occurs a zone of garnetiferous gneiss, a fairly large lenticular mass of which yielded the specimen 44/204. Under the microscope (22141) it shows quartz, biotite, garnet and staurolite. The biotite is light yellow to dark greenish brown in colour. Garnet and staurolite are diablastic and contain inclusions of quartz. Small flakes of biotite, needles of tourmaline and grains of magnetite are present. Bundles of sillimanite fibres are found in the biotite, and they often go through more than one individual crystal of biotite uninterruptedly. Some bundles are bent around the garnet porphyroblasts.

Garnetiferous gneiss.

Another, a gneissic rock (44/208 : 22145), was collected near Bihabali (22° 6′ : 84° 26′). It is similar in mineral composition to

the rock described above, and is penetrated by stringers of vein quartz. A little felspar and apatite are also present.

The highly schistose, somewhat carbonaceous, rocks (20035 and 20036) from the zone just south of Raiboga, show garnet, biotite and staurolite porphyroblasts in a fine-grained phyllitic groundmass. Some of the porphyroblasts are diablastic. The staurolite contains dusty carbonaceous inclusions. The ground-fabric shows quartz, biotite, chlorite and tiny laths of tourmaline.

A band of garnetiferous schists passes through Potob and Hatugara in Ranchi near the Gangpur border. Certain bands here contain staurolite. A specimen from this occurrence (37/986 : 19942) shows quartz, garnet, biotite and staurolite. The staurolites in the thin section are highly diablastic and show inclusions of quartz and, in one case, of garnet. The porphyroblasts frequently have irregular edges, particularly when garnet and staurolite adjoin. The quartz inclusions in some of the staurolite porphyroblasts tend to be arranged parallel to some of the faces of the latter.

A specimen collected from the railway cutting N.N.E. of Theralibahal (38/39 · 19979) is a light greenish mica-schist, showing knots of black biotite crystals. Under the microscope, the groundmass is seen to consist of muscovite and quartz with a little magnetite, chloritic material, tourmaline, staurolite, biotite and penninite, the first two especially being full of inclusions. All the crystalloblasts lie at an angle to the schistosity.

An almost universal character of the garnetiferous schists examined is the evidence in them of the rotation of the porphyroblasts. This applies not only to garnet, but also to biotite, penninite and staurolite. Garnet and biotite being more abundant than the latter two minerals, have very frequently been observed to show this character. The cleavage directions of biotite and the elongation of the inclusions in garnet, which usually are coincident among themselves, show to a large extent the original direction of 'lie' of these minerals. But this original direction always shows a marked deviation from the direction of schistosity of the groundmass in the slices. The latter indicates the direction of the final compression. The angles between these are usually around 30° but cases have been observed where they range up to 90°. It is possible that the porphyroblasts themselves have been rotated to a greater or less extent by the final compression, but it is

Rotation of porphyroblasts.

Its significance.

noteworthy that the final pressures which acted on these rocks have not been able to bring the porphyroblasts into line with the much softer, usually micaceous, constituents of the groundmass. Instead, the groundmass has flowed around and moulded itself on the island porphyroblasts. It should be possible to determine the direction of the previous stresses by very careful studies of field and microscope sections whose orientations are noted on the spot and correlated. I was not able to undertake this study, owing to the limited time at my disposal.

Evidence of regressive metamorphism.

In connection with the porphyroblasts it has been noticed that there is definite evidence of the final folding movements having produced conditions favourable for regressive metamorphism. Several of the rocks containing the garnet would at first sight be called phyllites. The phyllitic stage, however, was superposed on rocks which had previously been subjected to 'meso' or even 'hypo' (kata) grade of metamorphism. The lower temperatures and high stresses characteristic of the epi-grade produced minerals which are in keeping with the conditions of equilibrium then present. In thin sections 19975, 19978, *etc.*, the garnet shows alteration, along the edges, to chlorite, in addition to the limonitisation which is almost always present. The biotite porphyroblasts have sometimes been altered to chlorite. In the groundmass itself, chlorite is frequently present and strain-slip cleavages have developed. These evidences show that there has been some effort at reconstitution of the material, but the resistant minerals have to a large extent withstood the effect of the new conditions and have survived as relics of the more intense conditions under which they were originally formed. These rocks have therefore acquired the structures and peculiarities consequent on 'phyllonitization'[1] and have thus become what have been called 'diaphthorites' by F. Becke[2].

Chemical Composition.

Three analyses of rocks described under the above group are given in the next table. The rocks selected are a schistose biotite-gneiss, a biotite-schist and a muscovite-schist respectively.

[1] E. B. Knopf, *loc. cit.*
[2] F. Becke, Über Diaphthorite. *Min. Petr. Mitt.*, XXVIII, pp. 369-375, (1909).

TABLE 4.—*Analyses of mica-schists.*

—	Analyses. 1	2	3	—	Niggli values. 1	2	3
SiO_2 . .	47·51	50·72	55·03	si	120·0	121	226
TiO_2 . .	1·14	1·07	1·82	al	27·6	21·0	68·6
Al_2O_3 . .	18·13	11·02	29·67	fm	46·1	46·5	10·0
Fe_2O_3 . .	6·03	2·08	1·08	c	7·4	24·0	1·9
FeO . .	8·73	10·61	1·03	alk	18·9	7·6	19·6
MnO . .	0·15	0·22	trace	mg	0·32	0·46	0·01
MgO . .	3·86	5·06	0·01	k	0·44	0·17	0·51
CaO . .	2·72	9·75	0·12	c/fm	0·16	0·51	0·18
Na_2O . .	4·26	2·73	2·42				
K_2O . .	5·15	0·89	3·89				
H_2O+ . .	1·16	1·07	3·51				
H_2O- . .	0·21	0·22	0·07				
P_2O_5 . .	0·05	0·18	0·06				
FeS_2 . .	0·13	..	..				
CO_2 . .	trace	trace	n. d.				
TOTAL .	100·18	100·35	99·51				
S. G. .	2·92	2·68	2·81				

1. Biotite-gneiss (40/40) from the bank of the stream near Babalmohan (22° 23′ : 81° 20′). Much green pleochroic biotite, a little muscovite, some quartz, orthoclase, ? oligoclase; some fine lenticles of quartz in the foliation planes. Analyst— F. Raoult.
2. Biotite-schist (37/891) from an exposure north-east of Kuriabera (22° 22′ 30″ : 86° 7′). Light greenish grey phyllitic rock with much biotite and quartz, subordinate muscovite, plagioclase and a little iron ore. Analyst—P. C. Roy.
3. Crinkled muscovite-schist (44/173) from the hill two miles north-east of Pongdih (22° 0′: 81° 42′) Contains besides muscovite and quartz, a little ilmenite, leucoxene and tourmaline. Analyst—P. C. Roy.

Of the three analyses, the first two, which represent biotitic rocks, are comparable. The first is poorer in lime and richer in alkalies and potash when compared to the second. The differences in the relative proportions of the molecules in the rocks are brought out in the Niggli values shown by the side of the analyses.

Chlorite-schists.

Although the mica-schists and phyllites contain small amounts of chlorite and sometimes even moderate quantities, chlorite schists

with chlorite as the dominant mineral are distinctly rare. A few cases were observed where chlorite-schists form small lenses amidst the more common mica schists, for example near Rampur and Rukedega east of Kumarmunda, near Tunmura, in the Bondrai hill near Bisra, near Jharbera and a few other places.

Chlorite-bearing mica-schists have been noticed at many places, these consisting mainly of quartz and biotite with subordinate chlorite. The last is in some measure derived from biotite, but in some cases it may be original, and independent of biotite.

The chlorite-schists consist mainly of chlorite (penninite or less frequently clinochlore). Some are chlorite-quartz schists (19962) which may contain a little tourmaline. From near Rukedega was collected a rock which contains only light green chlorite and magnetite. Others contain ilmenite and sphene as accessory minerals.

Their occurrence in small isolated lenses in the anticlinorium, and much more frequently- as chlorite-mica-schists in the Iron ore series, suggests that they were probably patches protected against higher metamorphic conditions. Some of them however seem to indicate that they were originally mica schists subjected to epi-grade conditions with the concomitant partial conversion of biotite to chlorite.

QUARTZITE, QUARTZ-SCHIST AND OTHER ROCKS.

The quartzites, which occur as distinct bands in this area, include both the granular and massive varieties as well as those in which a distinct schistosity has been developed by shearing. The latter are here called quartz-schists and they include rocks in which varying, but usually small, quantities of micaceous minerals are present, which tend to emphasize the foliation. These sometimes grade into what may be termed highly quartzose mica-schists.

Quartzites.

Some of the quartzites form impersistent and thin beds amidst the schists. Others are well-marked and may persist for a length of several miles. One such will be noticed on the map forming a thin ribbon five to six miles north of the railway track between Rajgangpur and Rourkela. Several smaller ones will be found in other parts of the area.

In the Lifripara-Sirapgarh region as well in the south-eastern corner in the Bonai State, there occur several ridges of quartzites which grade into quartz-schists and occasionally into crush-conglomerates.

Colour.

The quartzites are pure white, buff, light brown or bluish grey in colour. The bluish grey and buff colours are perhaps the most common. The brown shades are due to the decomposition of the iron-bearing minerals in them, the iron being dispersed by surface waters, coating the grains and forming films in the cracks and crevices. The bluish and greyish tints are due to minute, dark, dust like inclusions in the component grains.

Texture.

In texture they are generally fine grained and equigranular, though a good deal of variation in grain size is to be noted in the different occurrences.

Some are so fine-grained that the individual grains can be resolved only under the microscope. A very fine-grained buff variety, which breaks into thin angular splinters and pencil-like fragments, was observed near the south-eastern foot of the Chutia pahar (22° 17′ 30″ : 84° 51′). A few small occurrences of dark lydian stone have also been noted.

Petrology.

The quartzites are mainly composed of quartz. Very small quantities of other minerals occur. Of these, muscovite and biotite are common. As remarked above, the bluish quartzites contain dusty inclusions of magnetite (probably carbonaceous matter in some). A buff quartzite from the southern bank of the Sankh river near Bilaigar contains some orthoclase and microcline while another occurrence near Biringatoli (22° 24′ : 84° 29′) is similarly felspathic. Excellent small crystals of magnetite are seen in a specimen (20147) collected from near Kuarmal. Fine sillimanite needles are found in the quartzites near Pandrisila and near Kahehua. Epidote grains have been seen in one. A brownish quartzite from near Tapsatoli (22° 15′ : 84° 24′) shows fine dendritic growths of limonite in the thin section (20201). There are some quartzites which are transitional to dolomite and limestone. These evidently represent siliceous bands deposited in association with the marbles. There are among them quartzites with only a few crystals of rhombohedral carbonates while others contain the latter in larger amounts (37/927, 37/942, *etc.*). Occurrences of such rocks are found near Sam Bamua, Hathibari, Purnapani and other places.

Quartz-schists.

In these rocks quartz is the dominant mineral, but it is practically always associated with a small quantity of mica. There are also cases in which chlorite, kyanite, sillimanite, felspars and iron-ores are found. They differ from the quartzites only in their showing a schistose structure, with consequent tendency to break into slabs. Evidences of shear are to be found in the slickensides and foliation joints, which are usually marked by a thin film of sericite or muscovite. They grade into grits and conglomerates when the constituent grains are of various sizes. There are some in which pebbles of jasper, and opaline or chalcedonic, translucent quartz have been noticed.

These include also a few tourmaline-bearing varieties. Such are found near Raichhapal and Hathibandha (22° 20′ : 81° 20′), and in the masses occurring in Bonai. Megascopically the tourmaline appears very much alike, but under the microscope, different absorption colours are noted in different occurrences:

Colourless to greenish grey (20091, 20204).
Bluish grey to dark inky blue (20138).
Colourless to greenish brown (20111, 20216).
Colourless to light orange (20110, 20112).

The colours obviously depend on the composition of the tourmaline, and especially the percentage of iron present.

Hornfels.

Rocks which are best called hornfelses, because of their compact, fine-grained, quartzose nature, occur in several places, both in the anticlinorium and in the Iron-ore series to the south, but the exposures are always small and lenticular, rarely if ever exceeding a few hundred square feet in area. The following short descriptions of the rocks from the more important exposures will give an idea as to their nature. The hornfelses are distinctly denser than the mica-schists, their specific gravity ranging between 2·84 and 3·25, the average for six specimens being 3·05.

The rocks are light grey or greenish grey in colour, the garnets present imparting a mottled appearance. Quartz is the most abundant mineral in all. A pale pink, markedly diablastic, garnet is present in practically all, in varying amounts. A diopsidic pyroxene, a green, usually strongly pleochroic amphibole, epidote and clinozoisite

are also common. Smaller quantities of magnetite, sphene, tourmaline and felspar are occasionally found.

A rock collected from near Dahijora (22° 15′ 30″ : 84° 27′) contains fine flakes of micaceous inclusions in quartz, in addition to garnet and a little tourmaline and magnetite. Another from the hill east of Khorla (22° 8′ : 84° 15′ 30″) shows needle-like clusters of amphibole in addition to quartz and pyroxene, and a little microcline and plagioclase. A little rhombohedral carbonate and tourmaline were found in a specimen from near Machhamara (22° 12′ : 84° 17′).

About half a mile to the north-west of Bankoba (22° 26′ 30″ : 84° 46′) on the Gangpur-Ranchi boundary is an exposure, 200 feet long and 5 to 10 feet wide. This contains quartz, amphibole and garnet. Some clino-ziosite and rare flakes of biotite were also observed.

Just south of the railway cutting, three furlongs west of Bisrapara (22° 21′ : 84° 46′), is a small knoll composed of similar rock occupying an area 60 feet by 20 feet. It consists of quartz, bladed crystalloblasts of actinolitic amphibole, and pink garnets with frayed-out edges. The latter two minerals are diablastic with inclusions of quartz. A little magnetite and rare plagioclase also occur.

About a mile to the west of Gopur (22° 22′ : 84° 35′) on the northern bank of the small stream, is a small lens of hornfels, consisting of fine-grained quartz, in which are found porphyroblastic hornblende and garnet. The hornblende shows several pleochroic haloes. A little felspar is observed in the groundmass.

In the area south of Kalunga, and particularly around Patua (22° 4′ : 84° 16′) and Khairband (22° 9′ : 84° 49′), there are several small lenses of similar rocks. They show pink garnets and pale green actinolitic amphiboles, both usually diablastic, and a fine-grained groundmass of abundant quartz and some felspar, most of the latter being plagioclase. Clinozoisite or very pale green epidote is generally present, as also iron-ore in small sporadic grains.

Maclaren[1] has observed a similar rock exposed near Mundaijodi (Mundajor), south-east of Rourkela, where—

'occurs a rock of strikingly holocrystalline appearance, but which on microscopical examination proves to be of sedimentary origin. It is made up of large crystals of a pale-green amphibole and of pink garnet, both enclosed in a matrix of granular quartz. Accessory minerals, as sillimanite and epidote, are also present........ According to Mr. Smith, who found it *in situ*, it there forms a thin band of 8 inches,

[1] Maclaren, *Rec. Geol. Surv. Ind.*, XXXI, p. 71, (1904).

in the argillites of the Dharwarian series, and lying parallel with their plane of foliation........'

It will be seen from the above descriptions that all the occurrences are garnet- and amphibole-bearing, some containing diopsidic pyroxene also. Their origin is rather obscure. None of the cases appears to have any connection with igneous contacts. Probably they represent highly localised patches of gritty calcareous mica schists subjected to more intense conditions of metamorphism than the surrounding areas. The presence of pyroxene indicates static pressure or thermal conditions, for, with directed pressure, it is converted into amphibole. In regional metamorphism involving extensive areas, such localised severe conditions, which denote the development of high temperature due to intense crushing, are possible, as pointed out by Harker,[1] who cites examples of biotite-hornfels and garnetiferous hornfels formed locally along thrust-zones in the Belgian Ardenne, and adds:

'Doubtless, at these localities the effective crushing, with the generation of heat, was in the sharply folded, hard, gritty bands, while the conspicuous effects of metamorphism are shown by the associated argillaceous beds..........About Libramont, where the metamorphism attains its maximum, the *cornubianite* type is developed, not only in nodules but in continuous bands, with biotite, garnet and hornblende as characteristic minerals'.

Calc-gneiss.

A peculiar gneissic rock occurs in the Tomkiapahar (22° 11': 84° 50') and in the road-cutting near Hathibandha, a few miles to the south of Panposh railway station. It is pale greenish grey in colour and medium to coarse-grained, frequently being banded owing to the segregation of the dark constituents in streaky fashion. The specimens collected from the exposures (19999 to 20002) show quartz, perthitic orthoclase, microcline, and much actinolite with pale greenish colour and weak pleochroism (Plate 14, fig. 4). Several of the amphiboles form good lath-shaped individuals giving an extinction angle of 17°-18° from the prismatic cleavage and are often patchily coloured, perhaps due to irregular distribution of the iron content. Some are colourless and may be nearly pure tremolite. Feathery radiating amphiboles are also seen. The presence of appreciable quantities of zoisite or clino-zoisite is an interesting feature.

[1] A. Harker, Metamorphism, pp. 332-338, especially p. 334, London, (1932).

A number of dirty-looking grains of sphene and few of what seem to be a diopsidic pyroxene are also to be found.

Veins of granite, pegmatite and aplite are common in this area. It seems probable that the occurrences represent the products of assimilation of some calcareous sediments by granite. Some of the exposures show the penetration by later pegmatite and quartz veins. From the mineral associations, they may be called calc-gneisses.

A somewhat similar rock occurs in an exposure of limestone close to a granite contact near the junction of the Ib and the Sapai, north of Bhasma. The rock (41/659 : 20774) consists of actinolite, diopside, quartz and felspar (Plate 14, fig. 1).

These rocks may be compared with certain Canadian occurrences described by Adams and Barlow[1]. In India similar rocks occur in Rajputana, Central Provinces and the Madras Presidency. Mr. C. S. Middlemiss[2] has given a full account of the calc-gneisses and amphibolites from the Idar State in Rajputana and discussed their origin. He has also referred to the work of Sir L. L. Fermor and R. C. Burton[3] in the Central Provinces and their views on the origin of the calc-rocks occurring therein. Though, in the present instance, calcite, pyroxene and some of the calc-silicate minerals are lacking, and the rocks are of very restricted distribution, the assemblage of minerals and association with granitic material are sufficiently characteristic to enable us to consider these rocks as hybrid in origin. The authorities cited above may be consulted for full discussions of this question.

Quartz-tourmaline-schist.

Occurrences of highly schistose rocks composed mainly of quartz and tourmaline have been observed in a few places. Of these the most conspicuous are found at the western end of the epidiorite mass of Burhaparbat (22° 27′ : 84° 5′), near Lasó in the centre of the anticlinorium and near Gaikanpali. They exhibit marked schistosity and banding and occur amidst the mica-schists and generally contain a high proportion of tourmaline. In several cases they are closely connected with vein quartz.

[1] F. D. Adams and A. E. Barlow, Geology of the Haliburton and Bancroft areas. *Dept. of Mines, Canada, Mem.* No. 6, pp. 103-120, 164 *et seq.*, (1910).
[2] C. S. Middlemiss, The geology of Idar State. *Mem. Geol. Surv. Ind.*, XLIV, Pt. 1, pp. 10-22, 42-48, (1921).
[3] *Rec. Geol. Surv. Ind.*, XLV, pp. 100-102, (1915).

The abundance of tourmaline in them suggests the influence of granite in their formation. It is likely that mineralising solutions from granite were responsible for converting the ferromagnesian constituents of the mica-schists into tourmaline. Vein quartz may have accompanied the solutions, and under the influence of stresses a marked schistosity has been acquired. The residual solutions from the granite were rich in tourmaline, as evidenced by the abundance of that mineral in the pegmatites and vein quartz found over the whole region. But only in certain areas have the solutions been rich enough in boron to form these quartz-tourmaline rocks in abundance.

THE RAGHUNATHPALI CRUSH-CONGLOMERATE.

Lying over the Gangpur series is a zone of crush conglomerate which forms a conspicuous feature along the southern border of the anticlinorium. At the eastern end, two rather detached occurrences are seen, near Kolpotka and Sirka (22° 23′ : 85° 7′ 30″). From Jaraikela, however, it can be followed almost as an uninterrupted ridge up to Ringan (22° 7′ 30″ : 84° 18′) and then at intervals up to Amasranga (22° 1′ : 84° 11′). It is a zone conforming in strike to the other members of the Gangpur series, having an E.-W. trend in the middle, and a N.E.-S.W. trend at either end. At the eastern end of the Mahabir pahar (22° 8′ : 84° 20′) it executes a sharp double bend, which is also reflected in the adjoining mica-schists and marbles near Purkapali.

The dip of this zone is generally very steep towards the south, and frequently vertical. The conglomerate portion is generally on the south, being underlain by finely banded phyllite, and intercalated with fine-grained to gritty quartzites.

To the north of the anticlinorium this horizon loses its identity and is largely represented by gritty phyllites with occasional development of quartzite. A thin quartzite band can be seen extending from Amko (22° 25′ : 84° 37′) to Rengarbira (22° 26′ : 84° 42′). Further east the highly quartzose schists form a range of small hills passing through Baraibera (22° 26′ : 84° 48′) and Potob, at which latter place a distinct quartzite ridge is seen. It is not possible to identify this zone still further east.

To the west of Amko again, the compression has been so intense that the over-lying Iron-ore series has been accommodated within

a small thickness. The granite batholith has replaced much of the Iron-ore series to the west, but this zone may probably be present for some distance parallel to the margin of the batholith.

In the western area around Lifripara, the Gangpur series does not show its characteristic divisions, but from the occurrence of a marble zone it is inferred that this series is comprised in the area between the two well-marked ranges of micaceous quartz-schists situated equidistant from Lafripara to the north and south.

Crushing and shearing are evident in the Raghunathpali zone particularly in the portion between Kolpotka and Amasranga. Crush-zones are also evident, in somewhat less degree, in the Lifripara area and in the Amko band. In an area so highly folded and in which the harder bands generally show effects of intense shear, it is almost impossible to find evidences of thrusting. Moreover the presence of mica schists as the prevalent formations in the whole succession and the absence of rocks with distinguishing characters in the area of the Iron-ore series adjoining the Gangpur anticlinorium are factors which obscure such evidence as may be present.

As remarked in the chapter on the structure, the assemblage of rocks in the anticlinorium is not repeated outside it, either in the north or south. This seems to be a sufficient indication that the Raghunathpali stage marks off the Gangpur series and separates it from the Iron-ore series. A thrust movement along the zone may therefore be assumed, though not definitely demonstrable.

A general description of the crush-conglomerates of the Raghunathpali stage has been recently given by the present writer.[1] The conglomerate occurs as a band intercalated with quartz-schists. It varies in thickness from place to place but scarcely ever exceeds 100 feet, and frequently grades into grits when followed along the strike. The pebbles are thin and lenticular with elliptical sections, flattened along the plane of foliation. They consist mainly of quartzite and micaceous quartzite and to a smaller extent, biotite-quartz schist. In a few cases, granite (near Kolpotka) and tourmaline-quartz rock (Mahabir pahar) have been recognised amidst them. The pebbles are well rounded and show films of mica on their flat faces with slickensides. The groundmass is schistose, containing much mica and finely granulated and crushed quartz. Some cases have come under observation in which there is little difference

[1] M. S. Krishnan, On some crush-conglomerates of Dharwar age from Chota Nagpur and Jubbulpore. *Rec. Geol. Surv. Ind.*, LXVII, pp. 455-462, (1934).

between the material of the groundmass and that of some pebbles. The presence of granite and tourmaline-quartz rock in the pebbles shows their derivation from some pre-existing granite mass, while the identity of material in some cases between the groundmass and pebbles shows their autoclastic nature. From these characters it is concluded that these crush conglomerates represent a bed of original sedimentary conglomerate, which by shearing has locally acquired an autoclastic character. For further details and discussion, the paper above referred to may be consulted.

CHAPTER X.—THE IRON-ORE SERIES.

IRON-ORE SERIES.

The Iron-ore series includes all the rocks exposed in the region surrounding the anticlinorium. It thus comprises the formations in the strip of country streaked with epidiorite sills in the north-east; around Anandpur and Manoharpur in the east; in Gangpur south of the crush-conglomerate zone, and in Bonai and Bamra; to the north of the quartzite hill passing by Sarapgarh and Ujalpur in the north-west, and also the schist-belt between Talsara and Bandega.

By far the most abundant rock-type in this series is phyllite or mica-schist, intercalated with which there are quartzites, quartz-schists, carbonaceous phyllites and numerous epidiorite sills. On the north, this series has been penetrated by granite which has assimilated much of it. A few small lenses, presumably of an older granite, are present in the neighbourhood of Jara. A tiny patch of granite, which is the edge of a large mass in Bonai State, peeps in at the south-easternmost corner. Lastly there are two small bands of a peculiar, sheared, chloritic conglomerate, also in the south-east corner.

The petrographic characters of the mica-schists, carbon-phyllites and quartzites are so similar to those of the Gangpur series that it is scarcely necessary to repeat them here. It will be sufficient to touch upon them very briefly.

The mica-schists show varying grades of metamorphism. Around Anandpur and Manoharpur, they are dominantly phyllitic. In the other parts they have reached a much higher stage. They are frequently quite rich in quartz, a factor which accounts for their rugged physiographic expression in most of their exposures.

Petrographically they comprise biotite- and muscovite-schists. Chloritic schists are common, as for instance in the Anandpur area. In the hillock just north of Barghat and in the hill south of Bisra there are chloritic schists composed of pale green chlorite with magnetite grains and quartz. There is a zone of micaceous calcareous flags which can be traced from near Potob to Pharsa, through Dhelsara, over a distance of nearly six miles. Its width, in the exposure in the Deo river at Dhelsara, is about 450 yards,

The rock varies from an impure limestone to calcareous shaly phyllite (45/752, 45/753), and parts of it are likely to be of economic importance. Slightly calcareous phyllites occur also south of Bisra and near Manoharpur.

A sandy, greenish and purplish phyllite occurs just north of Ramjhori, forming a band half a mile wide and some five miles long. It grades into ordinary phyllite in all directions. Garnetiferous and staurolite-bearing zones are also present. One such is found passing through Potob and Hatagara. Another lies alongside the prominent sill extending from Gailo to Rabga. Garnetiferous rocks are found near Chota Ramloi and Mundajor south of Bisra, and Malidih south of Rajgangpur. Thin bands of garnetiferous gneisses occur near Buchkupara and Bihabali, as already described on page 72.

The quartzites and quartz-schists are particularly well developed in the south-east. They are almost always sheared and break into rough slabs along planes of schistosity. They comprise muscovitic, slightly ferruginous and occasionally tourmaline-bearing varieties, which may be fine-grained, gritty or even conglomeratic. Conglomeratic bands are seen in the Gamburu ridge (an excellent section of which is seen in the Champajharan pass through which the Raghunathpali-Bonaigarh road has been aligned), in the Bhaisamunda pahar, near Kusumdih, etc.

The pebbles in these are mainly of sedimentary origin, though occasionally autoclastic elements may be present. A sillimanite-bearing quartzite is present in the hill south of Kahchua and another with kyanite in the hill south-west of Jara.

The carbonaceous phyllites and schists are very similar to, and lithologically indistinguishable from, those occurring in the Gangpur series. The occurrences however do not form persistent beds but disappear when followed for a few miles along the strike. A band adjoining the epidiorite near Kichinda has been extensively silicified, and in some places almost entirely replaced by silica.

Brecciated rocks.

There are certain restricted linear zones in the area under consideration, where, as a result of faulting, brecciated rocks have been developed. These are distinct from the sheared grits and conglomerates which form the Raghunathpali zone, and the quartzites

and quartz-schists of the Bonai region. These latter have distinct stratigraphic positions in the sequence of formations and are clearly the result of the crushing and shearing phenomena accompanying the orogenic movements of the late Dharwar period.

The fault-breccias to be described here may either belong to the same period of movements or may have appeared at a later stage. Some of the rocks involved, as will be seen below, are pegmatitic and granitic, and all have been generally recemented extensively by secondary silica. It is possible that these fault-breccias were generated in faults appearing during the waning period of granitic intrusion, or indeed even as late as the time of post-Gondwana faulting.

There are two types of these breccias. The more common type is quartzitic, and the other granitic. The former, because of their comparatively greater resistance to weathering, form conspicuous ridges, and comprise the following occurrences:—

1. One mile north of Bandega along the Gangpur State boundary. This is over a mile and a half long, trending in a E.10° S. - W.10° N. direction.
2. The Matipahar (22° 18′ : 83° 48′) and another ridge a mile to the east of it are practically in alignment. The total length, including the gap between them, is about three miles. It will be noticed that the brecciated pegmatitic rock occurring near Kinjirkela also lies along the same trend-line, and may very probably denote a continuation of this same fault zone.
3. A ridge extending from Sundargarh to near Patrapali (22° 10′ : 84° 1′), with a long break in the middle. But in this break, at Tangarmunda, a small exposure of brecciated rock has been observed, so that there is little doubt that the zone is continuous and underlies the soil cover here.
4. A remarkably continuous ridge, extending over a length of more than 18 miles, from Tinkura (22° 9′ : 83° 55′) to Rainda (21° 55′ : 83° 58′) on the Ib river. The general direction is N.15° W.—S.15° E., but at Tinkura it veers round to the north-west. After a break, in which it is not recognisable, perhaps because of the absence of quartzite, it is again seen half a mile south of Handipani (22° 12′ 30″ : 83° 51′), but much attenuated and having a thickness of only some 30 ft. There are several

constrictions and bulgings along this zone, varying in width between a few yards and nearly half a mile.

The original brecciated material in these is a fine-gained, mottled, white to pink and light brown quartzite. It has been broken up into angular fragments and cemented by thin veins and veinlets of white crystalline or chalcedonic quartz. These latter frequently show evidence of their secondary character of having been deposited from solutions, and display banded and comb-structures (Plate 15, fig. 3) and occasionally cavities lined with tiny quartz crystals. The quartzite varies in grain size, some comparatively coarser portions being surrounded by zones of intense crushing and granulation. It contains black and brown dusty inclusions which are mainly ferruginous. Sericitic matter is very rare, but occurs sparingly in the Sundargarh exposure.

Two small occurrences of brecciated pegmatite, which are doubtless of the nature of fault-breccias, have been noticed. One of these is found just to the south of Kachharjor (22° 17′ : 83° 55′) and extends in an east to west direction for over a mile, with a break in the middle. The thickness of the zone is about 60 to 80 feet. Along the same trend, and about a mile further east, is a small ridge of similar rock, passing through the village of Kinjirkela. The rocks exposed in all these look very much like brecciated quartzite. One specimen which was collected from near Kachharjor (41/715 : 20829) was found to consist of quartz and orthoclase with a small quantity of microcline. Mica and graphic structure are rare. Granulated patches are common. Veinlets of secondary quartz cement the brecciated fragments together. The Kinjirkela exposure is also similar.

The other occurrence was observed near the place marked 777 on map, situated at about one and a half miles E. S. E. of Masnikani (22° 1′ 30″ : 84° 2′). The rock appeared at first sight to be a crushed bluish grey vein-quartz, but microscopic examination showed that it was a pegmatitic rock consisting of bluish quartz and subordinate felspar. The quartz is streaky in appearance and gives wavy extinction. Rare muscovite flakes also occur. The extent of this exposure is not clearly seen, since the area is much covered by soil, but the nature of the rock makes it clear that it occurs in a zone of crushing and brecciation.

CHAPTER XI.- EPIDIORITES AND AMPHIBOLITES.

GENERAL.

Distribution.

In several places in the area, both in the Gangpur series and the Iron-ore series, occur masses of basic igneous rocks which have been metamorphosed to epidiorite and amphibolite. They are particularly abundant in the eastern portion of the area under consideration. Structurally, the great majority of them are sills. One of these is associated with the upper carbonaceous phyllite zone for a long distance. It may be seen from near the trijunction of Ranchi, Singhbhum and Gangpur, trending nearly westwards, to Banki. Other exposures in the same zone are seen at a few places on the eastern end of the anticlinorium, as well as along its southern margin.

A number of other prominent sills occur in the Iron-ore series both north and south of the geo-anticline. The one stretching from Gailo to Rabga near the Bonai border is the best developed of these in the southern area. To the north of Birmitrapur there is a series of more or less parallel sills (? and some flows) which, when followed to the west, converge towards Targa, owing to the high compression of the strata in that direction. Most of these show much variation in thickness and branch into thinner sills and are intercalated with the schists. A few thin sills occur in the westernmost part of Gangpur State near Masabira. These are also apparently to be included in the Iron-ore series.

On the Bonai border there are a few lenticular masses of the same rock, while, to the east of the geo-anticline, in Singhbhum, a few small exposures are seen which are structurally dykes.

Phyllitic appearance.

The occurrences in the Ranchi district seem to show, in a few cases, a grading off of the margins into phyllites. The appearances however need not necessarily be real, since in a few cases the specimens collected from portions which looked megascopically like phyllites proved to be very fine-grained amphibolites composed mainly of pale actinolite. There is however the possibility that some of the epidiorite bands in Ranchi are of the nature of flows associated with tuffs. There are again the peculiar sheared chloritic conglomerates occurring near Thiatangar in the south-east corner of the mapped area, which are probably of a tuffaceous nature. These are described and discussed in a later section, p. 106.

It may be suggested that the association of one of these sills with the upper carbonaceous phyllite zone may be taken as proving that these occurrences are all flows and that the carbonaceous material is a tuff. This rests on the assumption that the carbon in these pre-Cambrian sediments is all of volcanic origin and not organic. This question is discussed in the chapter on the carbonaceous phyllites. Except doubtfully in the Ranchi occurrences and in the sheared chloritic conglomerates near Thiatangar, there is no definite evidence of any tuffaceous material, and even in these cases the evidence is not completely reliable. If the basic rocks represent flows, then their variation in thickness from place to place and their irregular distribution along the upper carbonaceous phyllite are difficult of explanation, since the flows should have spread out fairly uniformly over long distances in order to reach all the places where they are now exposed. The basic rocks are also remarkably uniform in composition throughout this zone, except for secondary silicification. They are not associated with the older carbonaceous phyllite zone except in one place (*i.e.*, west of Khatkurbahal). There is only one other zone where there are some associated carbonaceous phyllites, *viz.*, the Gailo Rabga band. The basic rock also occurs at different positions or levels in the carbonaceous phyllite at different places. The explanation seems to me to lie in the fact that the rock was intruded as sills in the carbonaceous zone, which, being a zone of weakness, was in a favourable physical condition which permitted easy shattering and penetration by a liquid magma which welled up along it. Once the magma gained access to this zone from its main basin underlying the Dalma region in northern Singhbhum, it easily followed the zone, penetrating and replacing it to various degrees of completeness. The older carbonaceous phyllite had apparently been much more compacted because of its greater age and the thickness of sediments overlying it, and hence it may not have been accessible to the basic magma.[1]

Association with carbon-phyllite probably fortuitous.

There is little doubt that these basic rocks are identical with the 'Dalma traps', which are considered by Dr. Dunn to be contemporaneous with the topmost portion of the Iron-ore series. Reasons have already been

Dalma-trap age.

[1] This has a parallel in the mica-peridotite sills which are closely associated with the upper and softer seams of coal in the Jharia coalfield.

given for considering the succession of rocks in the Gangpur anticlinorium to be older in age than the Iron-ore series. Hence the basic rocks would have intrusive relationships with the older series which was already present when they welled up.

Since the basic rocks were formed, however, they and the whole series of sediments were subjected to diastrophism on an intense scale, which converted the clay sediments into phyllites and mica-schists, and the intrusives into epidiorites and amphibolites. The original pyroxenes were converted into amphiboles and the basic plagioclases were albitised and epidotised. The comparatively large amount of ilmenite, leucoxene and sphene now seen in the amphibolites probably represent to a large extent the titanium content which originally was present in solid solution in the pyroxenes. Becke [1] has shown that at the lower temperatures and the different conditions of physico-chemical equilibrium obtaining during the metamorphism of basic igneous rocks, the titania in the original pyroxenes and amphiboles would be thrown out of solution and would be found as ilmenite, sphene and rutile.

PETROLOGY.

Physical characters.

The rocks are all dark and generally have a marked green colour. When much felspar, quartz or light coloured epidote is present, a mottled appearance is common. Weathered portions are more or less lateritised, and give rise to a dark chocolate-brown soil. The rocks are also markedly schistose, and break into thin slabs or columnar splinters. It is sometimes difficult to find the dip of foliation because of the excessive development of splintery structure.

In several places the rocks display a banded appearance (41/685, 41/708, *etc.*). This is generally due to the arrangement of amphibole in needles with their lengths parallel to the plane of schistosity. Some show the presence of thin veins of quartz, which may even be folded (41/712). In the sills near Masabira, thin films of silica were found along some of the joint planes.

The petrographic types include epidiorites, amphibolites and amphibole-schists, tremolite-schists and in one case a

[1] F. Becke, Über Mineralbestand und Struktur der Kristallinischen Schiefer. *Denkschr. d. Kais. Akad. Wissen.* (Wien). *Math.—Naturw. Kl*, Bd. 75, 1 Halbband, p. 5, (1913).

tremolite-calcite-phlogopite rock. The specific gravity, which was determined for eighteen hand-specimens collected from various places in the area, ranges in value from 2·976 to 3·236, with an average of 3·08.

Minerals present.

The rocks included here contain a green pleochroic amphibole as the chief mineral, but in some cases pale green or even practically colourless amphibole of tremolitic composition assumes importance. The amount of the other minerals is very variable. Quartz and plagioclase felspar are generally present. The latter is usually albitised with the simultaneous development of epidote and zoisite. Original pyroxene is rare, but has been found in some cases, partly uralitised. Chlorite is also sometimes seen. Among the minor minerals are calcite, magnetite, ilmenite, sphene and leucoxene, pyrite and rarely tourmaline.

Amphibole.

In the schistose types the amphibole is lath shaped or acicular and arranged parallel to the plane of foliation. In the coarse-grained and gneissic types, it tends to form stouter crystals which do not show the well-developed parallelism of the schistose types. Occasionally, rosette-like groups and feathery crystals are also to be seen (20109).

The most common type of the mineral is a dark green and high ly pleochroic (light yellowish green to dark bluish green) variety of hornblende (22115, 22122, 22143, *etc.*). In some cases (20053, 22124) the larger crystals of amphibole in the sections show a patchy or zonal distribution of colour, the margins being darker green in colour than the centre. Some, which were examined under convergent light, gave a negative optical sign and may therefore correspond with aluminous hornblende or smaragdite. In some cases these pelochroic amphiboles may be actinolitic. In different sections the maximum value of extinction in prismatic sections was found to be between 17° and 22°.

In several cases the rock was found to consist almost entirely of amphibole, the other minerals forming less than two per cent. of the area of the thin sections (22112, 22123, 22130, 22881, *etc.*). The amphiboles show excellent parallelism in general, but sometimes have a felted arrangement. In addition to the general mass of comparatively large-sized amphibole, some very fine, filiform to acicular, amphibole is developed at the junction of the felspar and the original ferromagnesian mineral (22100, 22107, 22124, 22134, *etc.*)

These intergrowths of felspar and amphibole needles are evidently products of metamorphism to which Sederholm has given the name 'symplektite' under the more general group name 'synantetic minerals'.[1] In some instances, very fine, somewhat vermicular, intergrowths of plagioclase or quartz and clinozoisite or zoisite have also been found at the junction of these minerals.[2] The dark green, pleochroic amphibole from a specimen (38/119) collected from the hill north of Jambahal was analysed with the result given below.

The rock, after crushing to pass through a 100 mesh sieve was separated by heavy liquid. The associated magnetite was abstracted by a magnet and the clean amphibole picked out for analysis under a low magnification microscope. This material had a specific gravity of 3·13 at 25° C. (determined by the pycnometer), and the following refractive indices, determined by the immersion method in sodium light :

γ - 1·646 ± ·002
α - 1·624 ± ·002
$\gamma - \alpha$ - 0·022

TABLE 5. *Analyses of hornblendes.*

—	Analysis.				—	Niggli values.			
	I	A	B	C		I	A	B	C
SiO_2 .	47·61	46·68	48·71	43·11	si .	90·9	93·6	84·4	86·1
TiO_2 .	1·60	0·35	0·81	1·32	al .	16·1	17·0	17·0	18·1
Al_2O_3 .	13·40	14·37	11·08	11·10	fm .	54·1	54·8	54·6	57·8
Fe_2O_3 .	2·80	4·00	2·30	4·97	c .	26·3	22·2	23·6	25·2
FeO .	8·41	8·20	10·72	13·04	alk .	3·2	6·0	4·8	4·0
MnO .	0·55	..	0·30	0·43	ti .	2·15	0·72	0·58	2·62
MgO .	11·16	11·71	11·70	9·85	h .	6·2	5·2	9·5	18·9
CaO .	12·06	10·32	11·46	11·70	mg .	0·61	0·61	0·62	0·48
Na_2O .	1·47	2·11	2·13	1·18	k .	0·09	0·22	0·17	0·42
K_2O .	0·15	1·06	0·05	1·27					
H_2O+ .	0·57	0·54	1·48	1·02					
H_2O- .	0·85	0·28		0·10					
P_2O_5 .	0·06	..	..	0·10					
S .	0·06	..	..	..					
V_2O_3 .	..	..	..	0·07					
TOTAL .	100·64	99·96	99·74	99·78					
S. G. .	3·13	3·20	3·17	3·22					

1. Amphibole from amphibolite (38/119) from the hill north [illegible] Gangpur State. Analyst P. C. Roy.

A. From amphibolite of Umhausen, Tirol. Analyst—L. Hezner (*Min. Petr. Mitt.*, XXII, p. 502, 1903.)

B. From diorite-schist, Kremstal, Austria. Analyst—J. Morozewicz. (*Zeits. f. Krist.*, XXXIX, p. 610, 1904.)

C. From amphibolite, Palmer Center, Mass., U. S. A. Analyst—W. F. Hillebrand. (*U. S. Geol. Surv., Bull.* 419, p. 266, 1910).

[1] J. J. Sederholm, On Synantetic minerals and related phenomena. *Bull. Comm. Geol. Finlande*, No. 48, pp. 44-46, (1916).

[2] J. J. Sederholm, *ibid.*, p. 60.

L. A. N. Iyer, A study of the granitic intrusions with their associated rocks in Ranchi and Singhbhum districts. *Rec. Geol. Surv. Ind.*, LXV, pp. 510, 514, (1932).

The green pleochroic amphibole from the amphibolite sill near Jambahal is therefore seen to be an aluminous hornblende, comparable with those whose analyses are given in the table. All of them have evidently been derived from metamorphosed basic igneous rocks.

From the analytical result of the amphibole under consideration (anal. 1 in the above table) the following molecules were calculated, using the formulæ given by Winchell.[1]

32[H_2NaCa_2 (Mg, Fe)$_4$ Al $Si_6Al_2O_{24}$] Hornblende type.
42[(Ca, Na_2)$_3$ (Mg, Fe)$_4$ Al Si_7AlO_{24}] Hornblende type.
18[Ca_2 (Mg, Fe″)$_3$Fe‴$_2$$Si_8$ O_{24}] Riebeckite-glaucophane type.
42[(Mg, Fe) Al_2 Si_4 O_{12}] Riebeckite-glaucophane type.

It should be noted that only the first of the above four molecules is identical with one of the formulæ given by Winchell, the other three corresponding closely with others given by him.

The amphiboles frequently contain pleochroic haloes around sphene[2] (20012, 20043, 20232, 20800, 20822, *etc.*), which mineral has long been known to give rise to this phenomenon because of its containing small quantities of radioactive elements.

Tremolite and actinolite.

Tremolite and actinolite have also been found as important constituents of some of these amphibolites. These form part of the bands in certain places, for example near the Gangpur boundary north of Nuagaon (22° 19′ : 84° 24′), near Kodumunda (22° 23′ : 84° 32′ 30″), Kumbakera, and other places which are mentioned in greater detail on a later page. Pale green actinolite is the chief constituent of the amphibolites at and around Purnapani (22° 4′ : 84° 44′), near Chandipos (22° 4′ : 84° 35′ 30″) and a few other places (20211, 22137, 22897, 22898, *etc.*). The tremolite and actinolite sometimes contain dust-like inclusions which may be ferruginous. The maximum extinction angle in prismatic sections is about 17° or 18°.

Augite rare.

Traces of original augite are found only in a few rare cases, as for instance in the occurrences represented by thin section 22100 from south of Deliburu (22° 2′ : 84° 57′), 22106 from near Mohra (22° 0′ : 84° 56′),

[1] A. N. Winchell, Elements of optical mineralogy, Part II, p. 239, John Wiley & Sons, New York, (1939).

[2] O. Mügge, Radioaktivität und pleochroitische Höfe, *Centralbl. f. Min., Geol. u. Pal.*, pp. 66, 144, (1909).

20793 from the lenticular mass one mile east of Maltoli (22° 17′ 30″ : 84° 11′), and 22868 from near Koranjo (22° 26′ : 84° 25′). In the first two cases, the augite shows twins with 'herringbone' structure, due to orthopinacoidal twinning and basal cleavage, though most of the material has been uralitised. In the last two, however, a few grains of unaltered, or pale green partly altered, augite still remain.

Felspars.

Felspar is fairly abundant in some (about 40 per cent. of the slide in 22121, 22122, 22876, *etc.*) while in others it ranges down to a small quantity (22098, 22124, 22134, *etc.*). Lamellar twinning has to a large extent been obliterated during metamorphism. Where it is clear, the maximum basicity corresponds to andesine-labradorite. In most of the rocks the metamorphism has resulted in albitisation of the felspars with the simultaneous production of minerals of the epidote group. Orthoclase and microcline have been noticed but rarely (22870 and 22898).

Epidote.

Epidote, zoisite and clinozoisite are fairly common. A vein composed of clinozoisite is found in thin sections 20807 and 21370. The epidote is generally rather pale coloured (20807, 20808, 22100, *etc.*) and cloudy and shows distinct but weak pleochroism.

Ilmenite and sphene.

Among the accessory minerals ilmenite and sphene are the most common. Skeletal growths of magnetite are seen in a rock from the hill south of Bisra (19909). These ilmenite grains are often surrounded by a shell of sphene (22876, 22884, *etc.*) which was apparently formed during metamorphism owing to the addition of calcium and silica. Leucoxene, the translucent to opaque white alteration product of ilmenite, is also seen. It has so far generally been assumed to be a variety of sphene but recent work shows that it is mainly an oxide of titanium.[1]

Other minerals.

Chlorite and calcite are also found in small quantities. The former is fairly frequently seen (22129, 20785, 20220, *etc.*) in the types which have undergone a somewhat lower grade of metamorphism than is necessary for the production of amphibolite. In general the species of chlorite

[1] Fay Coil, Chemical composition of leucoxene in the Permian of Oklahoma. *Amer. Mineral.*, XVIII, pp. 62-65, (1933).

seems to be penninite. The calcite is often associated with epidote but usually in very small amounts (22121, 19815, *etc.*). Biotite also has been occasionally found, but is partly altered to chlorite (22860, 22869, 19914).

Pyrite, tourmaline and apatite are the other constituents present. Of these, pyrite is more frequently seen than the others. The tourmaline is found in some of the tremolite schists, while apatite occurs sparingly in 22121 and a few other sections.

A few typical varieties of rocks of this group will now be described.

Epidiorite and Amphibolite.

About a furlong to the east of Damkura (22° 16′ : 84° 8′) occurs a small exposure of altered basic rock. It is dark green and fine-grained and consists mainly of needle like amphibole and abundant light green chlorite, the latter showing 'ultra blue' interference tints in thin section (20785). The chlorite is seen to be derived, in part, from the alteration of amphibole. The other minerals present are plagioclase, some quartz, sphene, apatite, ilmenite and leucoxene.

A small dyke found to the N. N. W. of Bourai (22° 21′ 30″ : 84° 55′) is an epidiorite with little or no amphibole. The thin section (19890) shows epidote, quartz, calcite, biotite and chlorite.

In the stream west of Kokerama an exposure of highly jointed amphibolite occurs. It contains (19941) much hornblende with subordinate biotite altering to chlorite, and quartz. A rock collected from the hill north of Jojodah (22° 27′ : 84° 59′) consists mainly of hornblende. The colour of the mineral is of moderate intensity, and the maximum extinction in prismatic sections is 19°. The accompanying minerals are quartz, albitised felspar, clinozoisite and epidote (19929). A specimen (37/896 : 19845) from an occurrence in the village of Binjo (22° 27′ : 85° 6′) contains hornblende, showing patchy distribution of colour. The plagioclase, which is fairly abundant, shows albitisation and is full of inclusions of amphibole and epidote, the latter clearly derived from the plagioclase. Ilmenite and calcite are also present.

Epidosite.

Two occurrences of a massive, light yellowish green, finely granular epidote-quartz rock were observed, one of them (41/647)

forming a low dyke-like ridge near Sikhipani (21° 59′ : 84° 14′), and the other (41/709) occupying a small area at the south-western end of a small hillock half a mile south of Gaikanpali (22° 23′ : 84° 3′). Both these outcrops are comparatively long and narrow. In thin sections (20761, 20823) they are seen to be composed of nearly equal amounts of quartz and light yellow-green granular epidote. The epidote is generally somewhat clouded by inclusions. Several grains of sphene are also found.

The Sikhipani exposure is somewhat lateritised at the surface, due to the weathering of the epidote with the separation of iron. Thin sections (20151 to 20153) of specimens collected from this exposure show epidote the colour of which is patchy.

From the field evidence it is not possible to say whether the two occurrences represent altered basic rocks or metamorphosed calcareous sediments. Harker [1] states that though rocks of the latter origin have been observed, they are not common.

Antigorite-schist.

Talc-schists are apparently rare in this area. An occurrence which looked like a talc-schist was found on the western bank of the stream west of Katepur village (22° 25′ 30″ : 85° 2′) forming a lens-like deposit, some 40 ft. long and 8 to 10 ft. wide. The rock is soft and rather soapy to the touch and very finely schistose with a pale green tinge. Under the microscope (19852) it is found to consist of extremely fine needles and plates which are mainly antigorite. Associated with and interspersed in these are flakes of talc.

The exposure is to some extent obscured by soil cover. Its length may be more than that given above. It adjoins the upper zone of carbon phyllite, which is accompanied by amphibolite, a short distance to the south-west. The stratigraphical position lends support to the view that it is the alteration product of a basic igneous rock, probably a pyroxenite or peridotite, which types are known to give rise to masses of talc or antigorite.[2]

[1] A. Harker, Metamorphism, (London, 1932), p. 267.

[2] *Ibid.* p. 275.

H. H. Read, On the zoned association of antigorite, talc, actinolite, chlorite and biotite in Unst, Shetland Islands. *Mineral. Mag.*, XXIII, pp. 519-540, (1934).

Serpentinised basic rock.

Near the northern end of the sill just south of Chandiposi (22° 2′ : 84° 56′) the basic rock (11/162 : 22102) is observed to be composed mainly of serpentine. The cracks in the mineral are filled up with dusty and granular iron-ore probably eliminated during the serpentinisation of the original pyroxene. Some very fine colourless needles of (?) amphiboles are seen along the margins of the serpentine areas. Some felspar is present but it is sericitised to a large extent.

Tremolite-schist.

The presence of tremolite-schists among the amphibolites and epidiorites of the area has already been mentioned. The important occurrences are briefly described below.

About a mile and a half north of Nuagaon (22° 19′ : 84° 24′) is a band of tremolite rock which is nearly half a mile long and 150 yards wide. The main constituent of this is tremolite which frequently shows radiate groups. Thin sections (20211) show colourless bladed tremolite with inclusions of carbonaceous or ferruginous dust, and subordinate pale pleochroic (colourless to light orange-yellow) tourmaline. Another similar zone, occurring a short distance to the north of the above, shows the same minerals together with some chlorite. The tourmaline in these seems to be a magnesian variety.

A large part of the basic rock exposure seen near Kodumunda (22° 23′ : 84° 32′ 30″) is tremolite-schist (38/122 : 20057, 20058). The thin sections show both colourless tremolite and pale green actinolite, together with a few grains of iron ore.

Portions of the basic sills in Ranchi, especially the large one passing through Targa and Bartoli, are composed of tremolite-actinolite schists. The main mineral is colourless tremolite or very pale actinolite. The rocks are pale grey or buff, with a greenish tinge, and because of their fine grain and high schistosity are easily mistaken for ordinary phyllites or mica-schists. Tremolite-schists were collected from this band near Targa, Kumbakera, Bartoli and Bhaorchaba. At the last place, the rock is composed entirely of tremolite (22896, 22897) with only a few grains of iron-ore and rare chlorite. Associated with the tremolite-schist were small lenses of tremolite-talc-schist (45/749 : 22898).

Another noteworthy occurrence is the portion of the large epidiorite band at and around Purnapani (22° 4′ : 84° 44′). Here also the rock appeared at first sight to be a chloritic schist or phyllite, but microscopic examination showed the constituents to be predominantly tremolite or iron-poor actinolite, with a little felspar, iron-ore, and chlorite.

The same band shows, at its eastern end, about three furlongs west of Gailo, an elliptical area where a tremolite-calcite rock occurs. A specimen from here (44/189 : 22128) shows abundant colourless radiating groups of tremolite associated with a fair amount of calcite and a little quartz and phlogopite. There is little doubt that this is part of the epidiorite band, and similarly derived from the parent basic igneous rock. It differs from the other tremolite-schists of similar origin in its containing much calcite, but the difference is only one of degree, since calcite has been observed in several other specimens of amphibolite of this area. The original composition of the basic rock in this patch, aided perhaps by mineralising solutions, may have been favourable for the development of more calcite than elsewhere, in association with tremolite.

Hybrid types.

In the areas occupied by granite, several small exposures of basic rock occur. All of them are evidently remnants of basic intrusions caught up by the granite, and isolated. Such basic patches or inclusions are to some extent the hybrid mixtures of the two types of rock.

In an exposure in the stream W. N. W. of Kurai, granite is found injected in very thin veins or sheets, *lit-par-lit* fashion, in the planes of foliation of amphibolite. The rock (41/708 : 20822) shows much green, strongly pleochroic amphibole constituting over 50 per cent. of the rock, the remainder being composed of equal quantities of quartz and zoisite or clinozoisite, and a little sphene.

At and around Tikra (22° 29′ : 84° 43′) some hybrid rocks occur. One specimen from here (22894) contains amphibole, quartz, orthoclase, microcline, oligoclase, sphene and apatite. Granite veins are abundant in the exposures. Around Gunghuti in Bamra State, the hybridised basic rock is a hornblende-gneiss similar in mineral composition to the Tikra specimen mentioned above, and contains abundant veins of microcline-bearing pegmatite. In part, it has

the characters of a dioritic gneiss, similar to another occurrence described below.

Mica-hornblende andesine gneiss. (Diorite gneiss).

A lens of fairly coarse rock of basic appearance occurs amidst the granite-gneiss near Dumarbahal (22° 11′ 30″ : 84° 7′). The exposure is about a mile long and a fourth of a mile wide, the length coinciding with the foliation strike of the gneiss. A specimen (40/180) taken from the marginal portion of the lens has the appearance of an amphibolite except for the comparative coarseness of the grain and a somewhat paler colour and mottled appearance. A thin section (20230) shows much felspar of the composition of andesine, much green hornblende with strong pleochroism, and a fair amount of biotite. The accessory minerals are magnetite, apatite and pyrite.

The appreciable amount of biotite occurring in this, together with hornblende and andesine, may indicate extraneous material incorporated in the basic rock at the time of metamorphism. Somewhat similar rocks are described by Harker [1] as having been derived from the metamorphism of calcareous and chloritic sediments. It seems however more probable that the rock is mainly, if not wholly, of igneous origin, since the amount of felspar is considerable. The exposure has essentially the appearance of the basic rock common in the region and is entirely surrounded by granite. The granite seems to have been intimately mixed with the original basic rock and to have formed, on recrystallisation, a rock of essentially dioritic composition and aspect. The solvent effect of granitic magma on basic rocks has been admitted by petrologists. Iddings [2] has described the solvent action of rhyolite on basalt with the production of dioritic types. Harker [3] has summarised several cases recorded in petrographical literature on this subject. Tyrrell [4] found rocks representing gabbro-granite mixtures, in Arran. He considers it probable that the homogeneous dioritic rocks in Arran are the final results of the complete solution of the gabbroidal rocks by the granite magma. This fact is well

[1] A. Harker, Metamorphism, (London, 1932), p. 266.
[2] J. P. Iddings *et al.*, Geology of the Yellowstone National Park : Part II, *U. S. Geol. Surv. Monograph*, XXXII, Pt. 2, pp. 430-432, (1899).
[3] A. Harker, Natural History of Igneous rocks, (London, 1909), p. 339 *et seq.*
[4] G. W. Tyrrell, The Geology of Arran. *Mem. Geol. Surv. Scotland*, p. 172, (1928).

established, though antagonistic to Bowen's reaction principle, as pointed out by Fenner.[1] The rock under consideration has the appearance of a primary igneous rock, but from the field relations the origin ascribed here seems to be the most probable.

In the occurrence at Ganghuti described above, the same process seems to have produced the rocks of dioritic composition. Here too there is evidence pointing definitely to admixtures between the two types of rocks, *viz.*, granite and amphibolite.

Hornblende-garbenschiefer.

A thin lenticular mass of rock which may be called 'garbenschiefer' is found just east of Parmanpur (22° 6′: 84° 24′). It is only about 10 ft. long and 3 to 4 ft. wide, and is enclosed by garnetiferous mica-schists. The rock (44/210) shows very abundant, large, needle-shaped crystals of amphibole, up to one centimetre long and about half a millimetre thick, set in a fine-grained matrix of quartz. It is distinctly schistose, the amphiboles showing some parallelism in arrangement.

Under the microscope (22147) it shows a ground-mass of quartz with some felspar and rare biotite. Much of the felspar is twinned plagioclase. The amphibole is strongly pleochroic and seems to be a species of hornblende. Small grains of magnetite are present in small quantity.

Similar rocks occur in few other localities but are more fine-grained, and not so characteristic in appearance as the one described above. These may probably represent basic inclusions in schists. Harker[2] speaks of *garbenschiefer* derived from calcareous grits, but similar rocks can also be formed from some types of igneous rocks. Hence one cannot be sure about the origin of such rocks when they occur in comparatively small-sized lenses.

From the above descriptions, it will be gathered that there are a few distinctive types among the rocks derived from the basic Dalma traps. They can be put partly in the 'amphibolite facies' and partly in the 'green-schist facies' of Eskola.[3] The amphibolite facies, according to that author, shows a good deal of

[1] C. N. Fenner, The crystallisation of basalts. *Amer. Jour. Sc.*, XVIII, p. 252, (1929).
[2] A. Harker, Metamorphism, (London, 1932). p. 209.
[3] P. Eskola, The mineral facies of rocks. *Norsk Geol. Tidssk.*, VI, 1 p. 155, 162-168, (1920).

agreement between the chemical composition and mineral assemblage. An amphibole is an essential constituent, with which one or more of the following may be associated: microcline, plagioclase, cordierite, calcium and iron garnets, diopside and wollastonite. This facies represents a higher grade of metamorphism than the green-schist facies. The latter is produced under conditions of considerable stress, corresponding to the epi-zone of Grubenmann. A large variety of rocks is possible in this facies, epidote, chlorite, albite, talc and serpentine being the characteristic minerals. When much calcium is present it first forms epidote, and the excess is left over as calcite, even in presence of silica. The original lime-silicates, when subjected to the conditions of this facies, are transformed into the stable epidote. Calcareous phyllites or 'lime-phyllites', in which calcite occurs with quartz and micaceous minerals, form a group in this facies.

Metamorphism.

In the regional metamorphism of basic igneous rocks the lowest grade is represented by chlorite-albite-calcite rocks. Epidote begins to appear soon after and persists into a later stage where the rocks are transformed into amphibolites. When the amphiboles appear in force, the accompanying felspar is not so sodic as albite, but is oligoclase or andesine in composition. These rocks can be called plagioclase-amphibolites, a term which might be applied to the great majority of the rocks described in this chapter. Sometimes they may consist entirely of green hornblende. In this case, as Prof. Lacroix [1] has shown, a pyroxene-plagioclase rock may be converted into an almost pure hornblende-rock, the hornblende then containing the components of felspar in its own composition. With further metamorphism, diopside and garnet begin to appear and the rocks tend to acquire a granular character. The series of progressive changes has been described by Harker [2], under the heading 'metamorphism of basic igneous rocks'.

In the rocks described here, the metamorphism does not seem to have been intense enough to produce the garnet- or diopside-bearing amphibolites. Though garnet is abundantly developed in the mica-schists of adjoining areas, the high pressures developed

[1] A. Lacroix, Sur la transformation de quelques roches eruptives basiques en amphibolites. *Comp. Rend. Acad. Sc. (Paris)*, CLXIV, pp. 969-974, (1917).

[2] A. Harker, Metamorphism, (London, 1932), pp. 278-286.

in the amphibolites may have been transformed into shearing stresses, which are favourable to the formation of hornblende rather than the more granular minerals. High static pressures would seem to be necessary for the formation of pyroxene and garnet. The plagioclase-amphibolites are very well represented and also rocks of the lower stages of metamorphism. It is clear that here, as in the case of the mica-schists, retrograde metamorphism has affected the rocks, with consequent saussuritisation of felspars and the appearance of epidote and zoisite.

It has been noted that some portions of the amphibolite bands consist of tremolite-schists. This would indicate that the original rocks were poor in alumina, probably more basic than a gabbro, and approximating to picrite or pyroxenite. In such alumina-poor rocks the place of aluminous hornblende will be taken by tremolite-actinolite as shown by Hess.[1] Talc-schists and serpentine would form from the ultra-basic magnesian rocks, when enough water is available. Usually, in regional metamorphism, the talc is the fibrous antigorite and may be associated with serpentine. The serpentine, however, will disappear when the stress exceeds a certain limit.

Chemical Composition.

Two typical rocks from the amphibolite group were selected for analysis, one containing the common, pleochroic, green hornblende and the other a pale, slightly pleochroic, actinolitic amphibole. (Table 6).

From the comparison of the typical amphibolite with two similar rocks (see p. 104), one from the adjoining district of Singhbhum, and the other from the British Isles, it is seen that they have very similar chemical characters. All the three are under-saturated with respect to silica, since olivine is present in the norms of all, and nepheline in two. Though it is probable that the amphibolite of Gangpur was derived from a basaltic rock, Daly's average of plateau basalts is seen to be richer in silica than this, and even contains a little normative quartz. It is likely that the original rock was somewhat more basic, or that some change in composition was effected during metamorphism.

[1] H. H. Hess, Hydrothermal metamorphism of an ultrabasic intrusive at Schuyler, Virginia. *Amer. Jour. Sc.*, XXVI, p. 404, (1933).

In the calculation of the norm I have followed Barth's suggestion [1] of showing the different constituents of diopside, hypersthene and olivine separately.

TABLE 6.—*Analyses of amphibolites (Plagioclase hornblende rocks).*

—	Analyses. 1	A	B	C	—	Normative minerals. 1	A	B	C
SiO_2 .	45·21	48·20	45·70	48·80	Orthoclase .	1·11	5·01	3·34	4·06
TiO_2 .	0·58	0·83	2·60	2·19	Quartz .	..	..	..	0·84
Al_2O_3 .	14·97	14·54	13·60	13·98	Albite .	18·61	16·78	18·09	22·02
Fe_2O_3 .	2·32	1·87	2·32	3·59	Anorthite .	28·03	28·37	15·61	21·48
Cr_2O_3 .	..	..	0·14	..	Nepheline .	1·56	..	7·24	..
FeO .	9·07	9·83	0·47	9·78	*Diopside.*				
MnO .	0·19	0·14	..	0·17	CaO. SiO_2 .	9·61	13·47	12·43	8·36
MgO .	10·61	7·88	10·53	6·70	MgO. SiO_2 .	6·02	7·23	8·13	4·52
CaO .	11·92	12·51	10·08	9·38	FeO. SiO_2 .	3·03	5·80	3·43	3·30
Na_2O .	2·56	1·06	3·74	2·59	*Hypersthene.*				
K_2O .	0·21	0·80	0·56	0·60	MgO. SiO_2 .	..	2·71	..	11·05
H_2O+ .	1·62	1·24	1·10	1·80	FeO. SiO_2 .	..	2·24	..	8·31
H_2O- .	0·14	0·02	0·01		*Olivine.*				
P_2O_5 .	0·20	0·22	0·26	0·38	Forsterite .	14·28	0·75	12·66	..
CO_2 .	1·02	..	..	..	Fayalite .	8·35	5·81	5·91	..
FeS_2 .	..	..	0·08	..	Magnetite .	3·47	2·08	3·35	5·21
					Chromite .	..	..	0·22	..
TOTAL .	100·52	99·54	100·28	100·00	Ilmenite .	1·37	1·52	4·03	4·17
					Apatite .	0·34	0·50	0·67	0·70
S.G. .	3·04	..	..	..	Pyrite .	..	..	0·08	..
					Calcite .	2·80	..	..	..
					Water .	1·66	1·26	1·20	1·80
					TOTAL .	100·07	99·53	100·32	100·01

1. Amphibolite (44/185) from the hill near Kichinda. Much green pleochroic hornblende with interstitial plagioclase and rhombohedral carbonate and a little iron ore. Analyst—P. C. Roy.

A. Inclusion of hornblende-schist in pegmatite, near Gupltu (22° 56′ : 85° 8′), Singhbhum. Hornblende, plagioclase and quartz, with a little sphene, apatite and epidote. Analyst—L. A. Narayana Iyer. (*Rec. Geol. Surv. Ind.*, LXV, p. 508, 1932, Analysis IX).

B. Hornblende-schist, 800 yds. N. 18° E. of Bougang, 2 miles W. by S. of Colmonell, Ayrshire. Brown hornblende, labradorite, a little biotite and iron ore in a well foliated assemblage of irregularly shaped grains. Analyst—B. E. Dixon. (E. M. Guppy: Chemical analyses of igneous rocks, etc. *Mem. Geol. Surv., Great Britain*, 1931, p. 112, analysis No. 434).

C. Daly's average of 48 Plateau basalts. (R. A. Daly: Igneous rocks and the depths of the earth, p. 17, New York, 1933).

[1] Tom. W. F. Barth, Proposed change in calculation of norms in rocks. *Min. Petr. Mitt.*, Vol. XLII, pp. 1-7, (1931).

Niggli values of the analyses of amphibolites.

	1	A	B	C
si	91·3	105·8	94·84	115·5
al	17·82	18·83	16·74	19·50
fm	51·10	46·41	52·60	49·73
c	25·79	29·16	22·40	23·79
alk	5·28	5·30	8·26	6·08
mg	0·63	0·56	0·62	0·48
k	0·05	0·21	0·09	0·15
c/fm	0·51	0·64	0·43	0·48

TABLE 7.—*Analyses of an actinolite-schist and actinolite.*

	Analyses.				Niggli values.		
	1	A	B		1	A	B
SiO_2 . .	54·00	56·00	55·12	si . .	105·7	100·1	107·6
TiO_2 . .	0·84	trace	.	al . .	1·2	1·2	1·7
Al_2O_3 . .	1·00	1·00	1·48	fm . .	69·4	69·5	69·1
Fe_2O_3 . .	2·82	0·10	1·06	c . .	27·8	28·5	27·0
Cr_2O_3 . .	0·11	..	..	alk . .	2·04	0·92	2·22
FeO . .	9·47	7·14	8·18				
MnO . .	0·18	0·10	..	mg . .	0·71	0·83	0·76
MgO . .	17·02	20·52	17·86	k . .	0·25	*nil*	0·34
CaO . .	13·04	14·03	12·78				
Na_2O . .	0·81	0·50	0·77				
K_2O . .	0·40	trace	0·59				
H_2O+ . .	0·45	0·80	2·08				
H_2O- . .	0·28						
P_2O_5 . .	0·05	..	..				
FeS_2 . .	0·09	..	..				
TOTAL .	100·51	100·19	100·06				
S. G. . .	3·08	3·062	3·059				

1. Actinolite-schist from the hill just south-east of Chandipos (22° 4′ : 84° 35′ 30″). The rock (44/200) consists almost entirely of actinolite, with a very small quantity of sphene, ilmenite and quartz. Analyst—F. Raoult.

A. Actinolite from cumberlandite. Analyst—C. H. Warren. *Amer. Jour. Sc.*, XXV, p. 36, (1908).

B. Actinolite from Kragero, Norway. Analyst—S. Hillebrand. *Min. Petr. Mitt.*, XXVII, p. 273, (1908).

The analysis of the actinolite schist shows that its composition is remarkably close to that of the two actinolites with which it is compared in the above table. It will be noted that the iron content is medium. It is interesting that the basic rocks have produced several fairly extensive masses of such actinolite schists. They probably represent portions rich in olivine or hypersthene, which subsequently became amphibolised.

Sheared chloritic grit and conglomerate.

Distribution.

Genetically connected with the epidiorites, but apparently forming an interlude in the sedimentation are some peculiar sheared conglomerates in the south-eastern corner of the area. There are two well marked lenticular bands here, conformably intercalated with the phyllites. They have the general appearance of epidiorites but contain large elongated and sheared pebbles of varying character. One of these extends from Silpungi (22° 2′ 30″ : 84° 56′) in a north-east direction to a point south of Nawagaon (22° 5′ 30″ : 85° 0′). This is over 500 yards wide at Karda, where it is well exposed in the stream north of the village. The other has nearly the same strike and is found on the north-western bank of the stream near Thiatangar (22° 0′ 30″ : 84° 55′ 30″), whence it extends in a S. S. W. direction into the area covered by sheet 73 C/13, where it can be followed alongside the Bonaigarh road for more than two miles. A further occurrence was noted in juxtaposition with the sill south of Chandiposi, at a locality one mile north-east of Barghat (22° 0′ : 84° 55′).

Megascopic characters.

Megascopically, the rocks (44/157, 159, 163, 164, 168) look like epidiorites, but are generally characterised by coarse gritty or conglomeratic structure. Some of them show evidence of crushing and shearing, the pebbles being drawn out and occasionally showing slickensided surfaces. The exposure on the stream bank near Thiatangar shows large ovoid pebbles of banded haematite-jasper, one of which is represented by specimen 44/165. Some of the pebbles are eight or nine

inches long. Pebbles of ordinary quartzite, white or pink and brown in colour, are also common.

Microscopic characters.

Under the microscope, they show much quartz in the groundmass as well as in the pebbles. The jasper pebbles consist of abundant fine-grained quartz and magnetite (or martite) with a tendency to develop crystal outlines. Some patches in the sections consist of chlorite, magnetite and quartz in intimate association. Clots composed almost entirely of magnetite are also seen. The groundmass shows chlorite, quartz, sericite and rhombs of dolomite (or calcite). In section 22103, a few felspars have been observed, including microcline.

The epidiorite (amphibolite) band south of Chandiposi consists of abundant pale actinolitic amphibole and albitised felspar. Along its margin is found an occurrence of the conglomerate (44/168). This differs from the other conglomerates described above, in containing much epidote and biotite. The groundmass shows much epidote forming a granular aggregate, alone, or in conjunction with quartz, chlorite, and iron-ore. The pebbles are composed of quartz and some biotite.

Origin.

All the occurrences of this peculiar conglomerate are in proximity to sills of epidiorite, one of them (44/168) apparently forming the marginal portion of a sill. The pebbles of jasper are undoubtedly sedimentary and so are presumably the quartzite pebbles also. The presence of felspar in the matrix may indicate an igneous origin or arkosic nature. From the characters described above, three possibilities suggest themselves as to the origin of these rocks. The first is that they may be purely sedimentary, the chlorite, epidote, etc., having been formed during metamorphism. The second is that they may be volcanic agglomerates or conglomerates derived by the sedimentation of tuffaceous volcanic materials mixed with pebbles of formerly existing jasper and quartzite and other clastic material. The third is that a highly mobile basic magma might have thoroughly, penetrated a porous and ill-compacted conglomerate, the mixed material being later crushed and sheared.

With a view to gaining a knowledge of the composition of these, the matrix of a typical specimen (44/164 from the stream bank near Thiatangar) was analysed, the result being shown in Table 8.

TABLE 8.—*Analysis of the matrix of chloritic conglomerate.*

Analysis.		Norm.	
SiO_2	50·40	Quartz	23·18
TiO_2	0·81	Corundum	4·18
Al_2O_3	12·20	Orthoclase	8·36
Fe_2O_3	3·61	Albite	25·69
FeO	8·14	Anorthite	4·17
MnO	0·15	Hypersthene (Fe)	10·42
MgO	4·28	Hypersthene (Mg)	10·01
CaO	2·38	Magnetite	5·33
Na_2O	3·01	Ilmenite	1·97
K_2O	1·43	Apatite	0·17
H_2O+	3·45	Pyrite	0·09
H_2O-	0·14	Calcite	2·55
P_2O_5	0·07	Water	3·50
CO_2	1·12		
S	0·05	TOTAL	100·63
Fe	0·04		
TOTAL	100·37		
S. G.	2·83		

Specimen 44/104 contains much quartz, some chlorite, sericite, magnetite, rhombs of carbonate and rare felspar. Analyst.—F. Raoult.

In comparing the above analysis with those of some typical igneous rocks, it is evident that the silica percentage points to an intermediate type, while the relative proportions of the bases as well as the mineral composition indicate a basic rock. This is well brought out in a comparison of the Niggli values, as shown in the following table.

TABLE 8-A.—*Comparison of the conglomerate matrix with some igneous types.* (Niggli values).

—	1	A	B	C
si	200·8	105	140	173
al	24·8	23	25	25
fm	54·2	43	44	43
c	8·6	24	18	18·5
alk	12·9	10	13	13·5
mg	0·40	0·45	0·63	0·46
c/fm	0·16	0·56	0·41	0·43
k	0·24	0·25	0·57	0·66
qz	+49	—35	—12	+24

A. Essexite-gabbro type (Niggli and Beger: Gesteins- und Mineral-Provinzen, p. 169, Berlin, (1923).
B. Lamprosommaite type (*ibid.*, p. 183).
C. Augite-minette, Kirschhauser Tal, Switzerland (*Ibid.*, p. 183).

A comparison of the Niggli values shows that there is a similarity in the proportions of the chief bases, except that the rock under description is poorer in lime and richer in the ferro-magnesian constituents and in silica. It is also seen that it approaches the lamprophyre types rather than gabbro.

The chemical criteria discussed by Bastin [1] may also be used in an effort to decide about the parentage of the rock, whether igneous or sedimentary. It shows high silica, an excess of soda over potash and of magnesia over lime. Alumina is only slightly in excess of that necessary for balancing the alkalies and lime on an 1 : 1 ratio. The result, though inconclusive, rather favours an igneous origin. It will therefore be reasonable to presume that much of the matter constituting the matrix is of igneous origin, and that there has been some admixture with sedimentary material, evidently during deposition. There is however little doubt about the sedimentary nature of the pebbles embedded in this matrix.

[1] E. S. Bastin, Chemical composition as a criterion in identifying metamorphosed sediments. *Jour. Geol.*, XVII, pp. 445-472, (1909); XXI, pp. 193-201, (1913).

CHAPTER XII.—GRANITE, GNEISS AND ASSOCIATED ROCKS.

Along the northern border of the area is found the most extensive granite region of Bihar. This batholithic mass of the Ranchi plateau sends out tongues into the schists of the Gangpur border, partly assimilating and enveloping the latter. One such tongue passes through Talsara and Sundargarh into the Sambalpur district. Another large mass lies in Bonai continuous with the exposure seen at Bazonia, in the south-east corner of the map.

The gneissic and non-gneissic portions are intermingled to some extent. In general it may be said that in the marginal portions of the large masses gneissic structure tends to be well developed. There are also a few small, apparently isolated, patches of granites surrounded by mica-schists, but these are undoubtedly minor offshoots from the main mass. These minor bosses or stocks are, in general, coarser and richer in pegmatitic rock than the main mass. It is evidently the close proximity of the granites that is responsible for the ubiquitous presence of pegmatite and quartz everywhere in the area.

The smaller masses of granite referred to above are situated in the following areas :—

1. Padampur (Ekma).
2. Itma.
3. Bhainslata.

In addition to the gneissic granites above referred to, which are probably all purely igneous in origin, there are composite or injection gneisses occupying considerable areas, especially around Sundargarh and to its west and south. Here the schists have been extensively granitised by the very intimate penetration and spreading of granitic material into them. As a result, the type of rock produced is a hybrid between mica-schists and granite and contains a fair amount of felspars.

Besides the above gneisses, there are a few exposures of another type of gneiss near the Gangpur-Bonai border between longitudes 84° 30′ and 84° 45′. This appears to have slightly different characters from the Ranchi granite and gneiss. It is associated with epidiorite, the contact between the two being very obscure and

covered by soil and debris. But the indications are that the gneiss is penetrated by epidiorite and hence is presumably older than the latter.

The rocks of this group, especially the pegmatites, aplites and non-gneissic granites, have specific gravities remarkably close to 2·65, varying only between 2·60 and 2·70. The gneisses, including the composite gneisses, give values between 2·65 and 2·85, the average for ten specimens being 2·73.

Granite.

The granite (as also the gneiss) imparts a fairly characteristic aspect to the topography and scenery. It weathers into 'tors' and forms a somewhat rugged country with sparse vegetation of the mixed type of forest. Streams flowing through it have a wild aspect owing to the large rounded boulders present in their beds and banks (*see* Plate 3, fig. 1, showing the Sankh near Mararoma). The granite country tends to form a plateau, so that the level rises from 780 feet near Sundargarh (highly granitised schists) to about 1,050 feet near Talsara (granite and gneiss) and 1,300 feet to 1,600 feet in Southern Ranchi (granite plateau). In the main granite area, two directions of joints are fairly prominent. The more pronounced direction is E. N. E.—W. S. W. and the other N. W.- S. E. The former, it will be noted, is the general direction of the strike of the rocks of the region. The specific gravity of granite, determined on several specimens, is a value differing very little from 2·65, while that of the pegmatites and aplite is around 2·63.

The typical granite is generally white or sometimes pale pink owing to the colour of the felspars. It is coarse in texture and contains quartz, orthoclase, microcline, oligoclase, muscovite, and biotite. Occasionally either muscovite(45/713 : 22864, 45/721 : 22872) or biotite (45/706 : 22857) may be present to the exclusion of the other mica, but the quantity is always quite subordinate. Among the felspars, microcline is very abundant, especially in the pegmatitic rocks. Oligoclase is subordinate to the other two species of felspars. Micro-pegmatite is occasionally seen (22857).

Tourmaline is a very common, almost constant, constituent both of the granitic and the pegmatitic phases. At Mararoma a few exposures were noticed where the tourmaline forms dendritic

segregation patches in granite (Plate 3, fig. 2). The mineral is the usual black variety, bluish grey and strongly pleochroic in thin sections. Garnet appears to be a primary constituent of the granite in some places (41/681, 45/721, 38/125, 38/111, etc.), for example in the Padampur Ekma mass, and near Thethaitangar (22° 30′ : 84° 31′). Other original constituents are magnetite and apatite. Epidote, which seems to be a product of low grade metamorphism, is also occasionally found (see below).

Gneissic granite.

The gneisses are particularly abundant in the marginal portions of the Ranchi granite mass at and near its junction with the mica-schists. The granite thus grades into gneiss. The gneisses are prominently banded and streaky, this being brought about by alternate bands rich in quartz and felspar on the one hand and in micas on the other. Crushing of the porphyritic felspars is also evident in some cases. The mica tends to arrange itself parallel to the direction of banding or flow.

A slightly gneissic rock of granodioritic affinities occurs one mile south of Bandega. A thin slice of the rock (41/695:20809) shows much felspar, comprising orthoclase and basic oligoclase, with finely developed lamellar twinning, some quartz, a fair amount of biotite some of which is altered to penninite, a little secondary epidote and grains of magnetite. Among the accessory minerals are apatite, garnet, magnetite, ilmenite and sphene. The presence of garnet in non-gneissic granite and occasionally also in pegmatite shows that it occurs as a primary magmatic mineral. In the gneisses, however, it may be derived either from the granite or from the assimilated or associated schistose pelitic constituents.

Composite gneisses.

In the area around Sundargarh, Bhasma and Sargipali and along the borders of the granite batholith and its tongues, there are composite gneisses and migmatites produced by regional granitisation. The general foliation of the schists is in many cases preserved, fine *lit-par-lit* injection being common. Plate 4, fig. 1, which is a photograph of an exposure of mica-schists with alternating coarse granite bands, in the Ib river at its juction with the Sapai *nadi*, shows this on a coarse scale. Here the granite bands

are one to three feet thick. In several places 'augen-gneisses' have been found where the 'augen' are usually of coarse felspar and sometimes of quartz. The platy minerals, biotite and muscovite, in these rocks are bent around these eyes. The large porphyroblasts are usually surrounded by finer granulated felspar and quartz, and are themselves often shattered. The margins of the porphyroblasts may also show granophyric or myrmekitic patches.

Finely banded gneisses in which the pelitic and granitic constituents are fairly distinct, and those in which the bands merge into each other, are also very common. Recrystallised products of assimilation are also observed, in which rich streaks and clots of mica afford evidence of the sedimentary constituents. Indeed, all gradations from mica schists on the one hand to granite on the other can be seen. In an exposure in the stream near Ghantbur, the effect of assimilation of mica-schist by granite is well seen (Plate 4, fig. 2). The borders of the mica-schist are indistinct and drawn out into wisps, with the development of much black tourmaline and occasional garnet, the place of the biotite in the schist being taken by these two minerals.

The mineral assemblage in these rocks consists of quartz, biotite *muscovite, felspar (orthoclase, microcline and acid plagioclase),* and minor amounts of tourmaline, ilmenite, leucoxene, sphene and apatite.

At the western end of the Kichmirpahar (22° 2′ : 84° 40′), in the hills north and north-east of Dumki, and in a few other places, augen-gneisses are well developed. The exposures are all lenticular in shape. and of various dimensions. In the hills two miles north of Pongdih (22° 0′ : 84° 42′) there are crinkled muscovite-schists and felspathic schists containing bead-like strings of felspars. Around Damkura and other places along the margins of granite, thinly banded injection-gneisses are common.

Epidotised granite.

Epidotisation of granite is seen in a few localities, and generally sporadically. In the river section east of Biringatoli a fairly coarse pink and green rock is exposed. Similar occurrences have been noted near Bandega, in the stream east of Bahmanmara (near Tildega), etc. The most striking occurrence is however that

of the crush-zone to the north and north-north-east of Kumbakera where a zone 250 yards wide can be traced from a point north-west of Kumbakera to north of Bhitbuna. Locally this becomes an epidosite. The epidotised granite (45/744 : 22893) contains quartz, orthoclase, much microcline, oligoclase, epidote and hornblende, the last mineral being much chloritised. In places, *e.g.*, near the western end of the band, the rock shows abundant epidote and a little quartz (45/741 : 22890). The epidote sometimes encloses brown dusty ferruginous inclusions and streaks of carmine-coloured piedmontite. Occasionally lumps of pure epidote rock can also be picked up.

This zone shows abundant signs of crushing, which is particularly conspicuous near the eastern end, where the rock is brecciated and penetrated by anastomosing veins of secondary quartz. In fact, the rock looks megascopically like a brecciated quartzite but a thin section reveals its granitic composition. The piedmontite is probably to be attributed to attack and replacement by mineralising solutions.

(? Older) Gneiss.

Several small exposures of gneissic granite are found in the area to the east, north and north-west of Jara (22° 1′ : 84° 39′). The largest of these is about three miles east of Jara, occupying an area of two square miles.

The typical rock (44/171) is medium grained, light pinkish grey in colour, and dotted over with dark minerals. A thin slice (22111) shows quartz, orthoclase, and oligoclase, the felspars being generally perthitic. Some biotite, muscovite and epidote, and a little magnetite and apatite are also found. The fine granulation in some parts testifies to the crushing which the rocks have undergone. A specimen from the exposure near Chuliam (44/198 : 22135) shows also microcline and a fair amount of biotite, the latter forming dark wavy layers bending around the *augen* of felspar. The rocks of this group are generally pink, and contain fair amounts of biotite. Tourmaline is rare, which is in strong contrast with the Ranchi granite and gneiss where this mineral is almost a constant feature. Garnet is also rare, but epidote seems to be present generally in small quantities.

This gneiss is distinctly foliated and probably belongs to a period of intrusion earlier than that of the Ranchi granite. The

mass around Dhengurpani seems to be penetrated by the epidiorite. This however is rather obscure and cannot be taken as settled.

Chemical composition.

Two specimens of granitic rocks were analysed in the Geological Survey laboratory, the results being shown in Table 9.

TABLE 9.— *Analyses of granitic rocks.*

——	Analyses.		——	Norm.	
	1	2		1	2
SiO_2 . . .	72·50	75 27	Quartz . . .	20 07	18 01
TiO_2 . . .	0 09	0 41	Corundum . . .	2 06	6 03
Al_2O_3 . .	15 40	15·27	Orthoclase . . .	27 27	22·82
Fe_2O_3 . .	0·10	0 05	Albite	35·50	11·10
FeO . . .	0·70	1·95	Anorthite . . .	2·76	3·89
MnO . . .	0·06	0·03	Hypersthene (FeO,SiO_2)	1·32	2·24
MgO . . .	trace	0·01	Magnetite . . .	0·23	0·03
CaO . . .	0 85	0 90	Ilmenite . . .	0·15	0·96
BaO . . .	nil	n. d.	Apatite . . .	0 54	0·17
Na_2O . .	3·00	1·68	Water	0·70	0·50
K_2O . . .	1·05	8·81	B_2O_3	0·80	..
H_2O + . .	0·75	0·46			
H_2O— . .	0·01	0·04	TOTAL .	100·34	100·64
P_2O_5 . . .	0·22	0·07			
CO_2 . . .	nil	nil		Niggli values.	
B_2O_3 . . .	0·80	n. d.			
S . . .	nil	n. d.	si	457·2	464·5
Cl . . .	nil	0 01	ti	0·40	2·37
			al	57·57	55·52
			fm	5·30	13·31
			c	5·68	5·07
			alk	31·44	25·17
			mg	0·00	0·01
TOTAL .	100·27	100·59	c/fm	1·07	0·45
			k	0·59	0·60
S. G. (25° C.) .	2·58	2 66	qz	231·4	265·8

1. Tourmaline-granite (45/718) from near Belkuba (22° 24′ : 84° 12′ 30″) Ranchi district; contains quartz, orthoclase, microcline, oligoclase, some muscovite and tourmaline. Analyst—P. C. Roy.

2. Pink gneissic granite (44/171), one mile north of Pongdih (22° 0′ : 84° 42′), Bonai State; contains quartz, perthitic felspar, oligoclase, some biotite, muscovite and epidote and a few grains of apatite and magnetite. Analyst—P. C. Roy.

Of the two analyses given above, that of the tourmaline granite corresponds closely with aplitic granite types. The gneiss however shows a deficiency of alkalies in comparison with granite. This is probably due to the effects of assimilation of argillaceous matter by this gneiss during intrusion.

Origin of the gneisses.

We have already seen that the large masses of granite in Southern Ranchi and Bonai, and their tongues and offshoots, are non-foliated. These represent the mass injected and crystallised under quiescent conditions. Portions of this mass, however, may show veins of aplite, pegmatite and quartz, and the development of porphyritic types. In the marginal portions a distinct gneissic banding is observed. The foliation in these is generally parallel to that of the adjacent schists. In some places there is also the development of the type called 'augen gneiss'. Proceeding from the granite into the schists, one observes an appreciable enrichment, in the rocks, of the micas, and particularly biotite, these being prominently displayed in streaky layers.

The gneissic banding may have originated in two ways. Near the margin of the schists it is probably the result of flow of the magma, influenced by the presence of large resistant masses of solid schists. In the marginal portions of the schists themselves, the banding is due to the penetration of the acid magma, in *lit-par-lit* fashion, along the planes of foliation. At the junction between these two types of rock, the effects of igneous contact, assimilation and recrystallisation, are best seen. Further in, the schists show a gradual decrease in the amount of granitic material. This does not however apply to pegmatite and vein quartz, which are prevalent everywhere in the area. Since it is admitted that these represent the residual and the most highly fluid portions of the magma, they should have been able to penetrate the foliated rocks with ease. At the same time, from their ubiquitous presence, we may infer that the whole region is underlain, at a short distance, by granite masses which gave rise to them.

Around Sundargarh, and to its south and south-west, there is a large area which has been intensely granitised. Some of the phenomena described by Sederholm[1] in the granitised rocks of

[1] J. J. Sederholm, On migmatites and associated Pre-Cambrian rocks of South-Western Finland. *Bull. Comm. Geol. Finland*, No. 58, pp. 75 *et seq.*, (1923).

Finland can be seen here. Hybrid and injection types of gneisses occur in abundance. Layers of schists, loosened by the penetrating granite, have been detached and partially assimilated. The two types of rock often show indefinite borders gradually merging into each other. Wisps of schist are often seen surrounded by granite, and thoroughly recrystallised.

Augen-gneisses are seen in some places. The minerals forming the 'eyes' usually felspar and quartz are often seen to have been strained and shattered. Around the 'augen', and especially along their flattened sides, are thin layers of granulated materials. The granulation and shattering may be attributed to the fact that the magma may have crystallised out partially while it was still being injected, the more fluid portions being strained off. With the accession of more fluid magma, the granulated and shattered portions would again be cemented.

It is also clear that dynamic forces were at work during the period of intrusion of the granite. If the masses affected were still plastic, they would be easily folded, whereas, if they were solidified, they would be shattered and milled. Evidences of brecciation of the earlier solidified portions, with subsequent cementation by pegmatitic and aplitic material, are also met with.

The granophyric and myrmekitic structures found in these gneisses are evidences of changes during and after crystallisation. The parallel seams and streaks of mica and occasional bundles of sillimanite found in these are, according to Harker,[1] evidences of hybridisation. The presence of abundant felspar in the schists also points to the same conclusion.

Aplite.

The marginal portions of the granite mass occasionally show fine-grained aplitic modifications. These sometimes also occur as veins.

A specimen (41/713) looking like a fine-grained white quartzite, was collected from a locality two furlongs east of Tildega. Here it is found as a dyke-like mass marked by boulders arranged linearly. A thin slice (20827) shows the presence of quartz, orthoclase and albite-oligoclase and a few little grains of garnet.

[1] A. Harker, Metamorphism, (London, 1932), p. 303.

A plexus of veins of similar rock occurs one mile south west of Bandega. This (41/697 : 20811) exhibits quartz and dominant felspar, the latter consisting of about equal quantities of orthoclase and microcline. Occasional nests of mica are also noticed.

Fine examples of veins of tourmaline-aplite are found in the granite near Kolokhandi and Sahanamara. A specimen from one of these (41/688 : 20802B) contains quartz and felspar and rare muscovite and apatite. Another from the same locality (41/689) shows quartz, tourmaline and muscovite. A few other examples are also found in the granites of Southern Ranchi.

Pegmatite.

Whereas aplite is a comparatively restricted type, pegmatite is very widely distributed. It is seen in the granite areas and its marginal portions as well as in the mica-schists in practically every part of the area mapped. It is particularly abundant in and around the small granite bosses and in the granitised areas around Kinjirma and Sargipali and the Talsara-Sundargarh-Bhasma belt.

The pegmatite veins consist essentially of coarse masses of quartz and felspar. Much of the latter is microperthitic microcline, while orthoclase is also fairly plentiful. Some of the above areas contain enough coarse felspar to be worth prospecting for that mineral for use in industry.

In several places the pegmatite contains crystals of tourmaline. A particularly good occurrence is that in the Bhainslata boss where fine black tourmaline crystals are found in abundance, some measuring up to seven inches long and one inch across. In other cases tourmaline crystals are found forming a network and rarely rather irregularly radiating groups. The pegmatite in some places also shows small 'books' of mica, up to two inches across; but these were in all cases found to be too small in size and too unattractive in quality to be of any economic importance.

In the small knoll at the Pahantoli hamlet of Malsara, veins of pegmatite, aplite and quartz-veins of different ages are seen cutting across one another in gneissic granite. They all apparently belong to different times comprised in the time-range of intrusion

of granite and its derivatives. The following sketch shows the relationships of the different veins to each other.

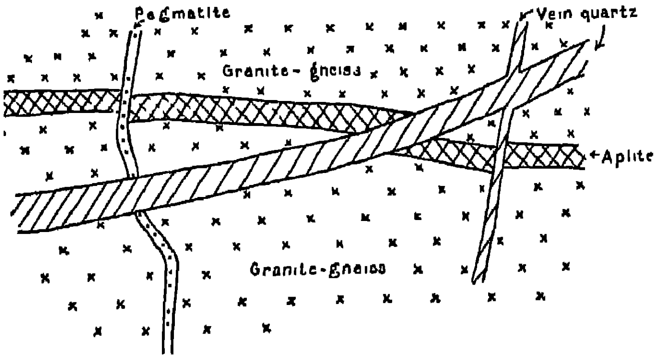

FIG. 4.—Sketch plan of granite-gneiss penetrated by later veins of different ages; near Malsara, Ranchi District.

The two occurrences of crushed granite or pegmatite, described under fault-rocks (crush-breccias) also belong here, but have been involved in fault movements and have therefore been severely crushed.

Vein-quartz.

Veins of quartz are universally present throughout the area and are mostly to be attributed to the presence of granite. Sometimes they are injected as thin veins along the foliation planes of the schists. Some attain large dimensions; in such cases they have been shown on the map, as for instance near Bamra, Damdapara, Sorda, Targa, Orga, *etc.*

In some cases the vein-quartz is associated with tourmaline, which occasionally forms a large proportion of the rock (37/906, 38/32, etc.). Near Surda, for instance, there are portions of the quartz vein or dyke in which tourmaline is more abundant than quartz. The tourmaline, when weathered, gives rise to a limonitic mass. The crystalls are often more than half an inch thick and show zones of different colours around the vertical axis.

Owing to movements after consolidation, the tourmaline-quartz rock has sometimes become markedly schistose, like the specimen 41/706 from Talsara near Birmitrapur.

A peculiar variety of tourmaline occurs in association with vein quartz in the following places:

1. Foot of hill north of Kadalka (M. 998)
2. Eastern foot of hill, south of Baribora (M. 989).
3. Near Kulagoja (M. 990).
4. Near Jojodah (M 991).

It is of interest to note that all these occurrences are close to epidiorite sills. The tourmaline occurs in masses breaking into acicular splinters, which are often somewhat bent and fractured. Sometimes the fragments are so compact as to be mistaken for a lydian stone or dark limonite.

Under the microscope the mineral is bottle-green or greenish grey in colour, becoming very pale green or grey in the position of the least absorption. The birefringence is to some extent masked by the body colour.

The refractive indices found by the immersion method are:-

$$\varepsilon=1{\cdot}617\pm{\cdot}002;\quad \omega=1{\cdot}642\pm{\cdot}002.$$

The mineral is uniaxial negative. It readily responds to a chemical test for boron. There is therefore little doubt that it is tourmaline.

CHAPTER XIII. THE GONDWANAS.

Previous work.

Early notices.

The occurrence of coal-bearing rocks in the Gangpur State was known as early as 1854 when Colonel Haughton mentioned the fact in a paper published by the Asiatic Society of Bengal[1]. Captain Saxton referred to a *nala* draining the coal-bearing formations and joining the Ib river[2]. In his paper published in 1859[3], Dr. Oldham refers to Colonel Saxton's remarks on the poor quality of the coal found in the Gangpur Rajah's territories, some 50 to 60 miles north-west of Sambalpur.

Ball's work.

Dr. V. Ball was the first to carry out geological work in the area. In a paper published in 1871[4], he describes the Gondwanas near Kosira (Kainsara, 22° 3′ : 83° 46′) and up the Baisundar and Jhajia *nalas*. He gives the measurements of sections met with between Tiklipara and Jhuprunga, and at the confluence of the streams north of Gopalpur. He measured three seams of coal, 4′ 7″, 3′ 10″ and 5″ respectively, in the Tiklipara-Jhuprunga section, the coal from the first of these giving 30·6 per cent. ash. His observations on coal between Rattansara and Ghogarpali and between the latter and Bhograkachhar are also given.

In a later paper[5], Dr. Ball shows that the Talchirs of this area fill up depressions in the metamorphics and are overlapped by the Barakars and the Upper or Hingir sandstones of Kamthi (Raniganj) age.

He describes the exposures near Rajpur (p. 105) and records the presence of a boulder-bed and shales in the Talchirs in the Godadia *nala* near its junction with the Baisundar. He gives the details of a section near Dulanga containing carbonaceous shales with intercalations of coal, and mentions other places where the

[1] *Jour. As. Soc. Beng.*, XXIII, p. 105, (1854).
[2] *Op. cit.*, XXIV, p. 185, (1856).
[3] T. Oldham, Preliminary notice on the coal and iron of Talcheer in the Tributary Mehals of Cuttack. *Mem. Geol. Surv. Ind.*, I, p. 9 (footnote), (1859).
[4] The Raigur and Hengir (Gangpur) coal-field. *Rec. Geol. Surv. Ind.*, IV, pp. 101-107, (1871).
[5] The Raigarh and Hingir coal-field. *Op. cit.*, VIII, pp. 102-121, (1875).

Barakars occur in the neighbourhood. A sample of coal from Dulanga analysed as follows, according to him (p. 120): –

	Per cent.
Moisture	11·0
Volatile matter	33·6
Fixed carbon	45·2
Ash	21·2

The Hingir sandstones, occurring on the Garjan hill near Garjanjor village (22° 2′ : 83° 38′) yielded fossil plants including *Glossopteris*, *Vertebraria*, *Schizoneura*, *Sphenopteris* and *Pecopteris* which were identified by Dr. Feistmantel as belonging to the Raniganj series. This is again referred to in Ball's paper[1] on the Geology of the Mahanadi basin.

Fossil plants.

Ball's work soon led to a decision for economic exploration of the field by bore-holes. Dr. King, who was in charge of this work, has described the selection of sites and the progress of the work done in a series of papers[2] published between 1884 and 1887.

King's work.

In 1886, three bore-holes were put down in this area, Nos. 1, 2, and 3 having been located respectively near Gopalpali (Gopalpur), Ratansarai (Rattansara) and Bankibahal. The second hole had to be abandoned after some time as the chisel broke in the hole and could not be extricated. Another hole, No. 2a, was commenced a short distance south of No. 2, but it did not strike coal before work was stopped at the close of the season. The results of the bore-hole survey are given below :—

Bore-hole exploration.

No. 1.

Total depth 190 ft.
Coal and carbonaceous shale (1 ft.), at 51 ft. depth ;
Coal and carbonaceous shale (7 ft.) at 67 ft. depth ;
Coal (6 ft.) at 76 ft. depth ;
Coal (25 ft.) at 164 ft. depth.

[1] V. Ball, On the Geology of the Mahanadi Basin and its vicinity. *Op. cit.*, X, p. 171, (1877).

[2] W. King, On the selection of sites for borings in the Raigarh-Hingir Coal-field. *Op. cit.*, XVII, pp. 128-130, (1884).

Sketch of the progress of geological work in the Chattisgarh division of the Central Provinces. *Op. cit.*, XVIII, pp. 169-200, (1885).

Boring exploration in the Chhattisgarh coal-fields (first notice). *Op. cit.*, XIX, pp. 210-234, (1886), especially pp. 216-219 and 233-234.

Boring explorations in the Chhattisgarh coal-fields (second notice). *Op. cit.*, XX, 194-202, (1887).

No. 2.

Total depth 163 ft.
Coal (16 ft.) at 9 ft. depth;
Coal (6 ft.) at 125 ft. depth;
Coal (6 ft.) at 135 ft. depth.

No. 3.

Total depth 189 ft.
Coal (20 ft.) at 11 ft. depth;
Coal (4 ft.) at 34 ft. depth;
Coal (10 ft.) at 82 ft. depth.

The coal samples from the bore-holes were practically all of poor quality. But a few samples from outcrops near by gave somewhat better results. On the whole, however, the area was very disappointing. Eight specimens of coal from outcrops near Rattansara gave the following range of composition:—

Results disappointing.

Moisture between 3·72 and 12·26 per cent.
Volatile matter between 24·98 and 32·82 per cent.
Fixed carbon between 29·20 and 50·60 per cent.
Ash between 6·52 and 42·10 per cent.

The average ash for the eight samples was 21·51 per cent. In the last paper cited above, Dr. King condemned the field while noting the fact that outcrop samples in several cases gave better results than the bore-hole samples.

No further published information is available of this area. It is known, however, that the Hingir Rampur Coal Co., Ltd., sunk some prospecting pits near Siarmal and Dulanga several years ago. The fact that the exploration was not continued by that firm may be taken as showing that the results were disappointing.

A recent but brief resumé of the information on this and the adjoining Rampur (Ib river) coalfield is given by Dr. C. S. Fox[1], who has revived the name Hingir (Himgir) coalfield for the strip of the Barakars extending from Rajpur to Amatpani on the northern rim of the Himgir basin.

[1] C. S. Fox, The Lower Gondwana coal-fields of India. *Mem. Geol. Surv. Ind.*, LIX, pp. 169-175, (1934).

Present work.

My work in this part of the country was mainly concerned with the mapping of the boundary of the metamorphic rocks with the Gondwanas. In the following account, therefore, only such facts as came under my observation while engaged on that work are given. For this tract of country, Dr. Ball gave the following succession of rocks[1] :—

6. Laterite.
5. Upper or Hingir sandstone.
4. Barakar.
3. Talchir.
2. Vindhyans.
1. Metamorphics.

Distribution.

The Talchirs occur here in the easternmost part, in the neighbourhood of Rajpur, but continue south into Sambalpur district. Their thickness was estimated at 250 ft. They are overlain by Barakar sandstones which form a strip of country one to three miles in width, abutting on the metamorphics to the north. These extend from near Rajpur on the Ib river to Amatpani on the border of the Raigarh State. Overlying these, and to their south, come the red sandstones of Kamthi age which occupy the greater part of the Himgir *zamindari*. The Mahadevas are supposed to overlie them in and around the town of Himgir.

Talchir series.

Sandstones and arenaceous shales of a pale greenish grey to buff colour occur around Rajpur in the Sambalpur district. They extend from the Ib river for a short distance to the west, up to Ranakata (21° 53′ : 83° 54′). The sandstones (43/202) are generally fine-grained and often felspathic and micaceous. They grade on the one hand into coarse sandstones and on the other into argillaceous fine-grained ones. The shales are pale green to greenish brown and in some exposures near Rajpur (specimen 43/203) are seen to be much jointed and to break up into irregular splinters and fragments.

[1] *Rec. Geol. Surv. Ind.*, VIII, Pt. 4, pp. 102-121, (1875).

Barakar series.

The Barakar sandstones overlap the Talchirs to the west, near Ranakata. Thence their northern boundary (with the metamorphics) proceeds west-north-westwards up to Dulanga (21° 57′ : 83° 48′) and from there north-westwards up to Kainsara. From here the boundary is very irregular but trends in a general northwest direction passing through Amatpani into the Raigarh State. In this part it forms a well marked bay convex to the south near Gopalpur, and sends two prominent ridges projecting eastwards from near Rajbahal. One of these presents a very steep and straight scarp, about 300 ft. high, extending for nearly two miles to the east-south-east from Amatpani, with a stream flowing at its base.

Boundary with the metamorphics.

In the northwest the sandstones contain layers of conglomerate. They show gentle dips (10°-15°) towards the south or south-south-west. Current-bedding is fairly common. They are generally of the nature of arkose, being soft and felspathic. But the weathered surface is comparatively hard owing to the brown limonitic coating or crust that is usually formed there by the ferruginous material drawn up to the surface by capillary action. In the course of weathering, the variations in the intrinsic hardness of the layers is brought out. The alternations of soft and hard layers plays a prominent part in the topography, the hard layers forming the flat-topped hills and the prominent members in the scarps. Plate 7, fig. 1, which is a view of an eroded thin layer of sandstone near Amatpani, shows in miniature the nature of weathering and sculpture in these rocks.

Nature of the strata.

The metamorphics to the north of the Gondwanas dip at high angles in different directions. A few sections, in which the junction of these two formations is clearly revealed, show the Barakars resting on the crystallines irregularly, with marked current-bedding. The irregular nature of the boundary also shows that the Barakars were deposited on an irregular basement of denuded Archaean rocks.

The Barakar sandstones vary from fine-grained to coarse-grained sandstones and grits (43/181, 43/182). Coarse conglomerates are particularly well exemplified in the hill one mile east of Rompia, where several pebble-beds occur at different horizons, varying in thickness from a few inches to several feet. These beds are, however, more

Sandstones and conglomerates.

frequent in the basal portions than higher up. The rock here (43/186) contains pebbles of various sizes which form more than three-quarters of the volume of the rock. The pebbles are mostly of white, translucent to opaque, quartz or quartzite, very well rounded and ellipsoidal. Occasionally we come across a few red jasper pebbles, derived from some earlier, probably Dharwarian, rocks. At the present day, beds of banded jasper are found in the adjoining district of Singhbhum, which might probably have extended nearer towards this area in Gondwana times, and contributed to the sediments which filled up the shallow basins of the Barakars. The individual sandstone beds range in thickness from 3 ft. to 20 ft. or more. They as well as the matrix of the pebble-beds, composed of felspathic sand and clay, are quite soft. Thin sections from some of the sandstones show quartz, orthoclase, microcline, muscovite, chlorite, semiangular grains of tourmaline and rare grains of iron-ore.

Minerals present.

A few of the hand-specimens collected in this area were crushed and the heavy minerals separated and examined. Specimen 43/181, from a spot one mile to the north-west of Amatpani, contained only 0·15 per cent. of heavy minerals in the specimen used, the rest being kaolin and quartz-sand. The heavy residue from this was found to be made up of the following:—

	Per cent.
Magnetite and Ilmenite	35
Zircon	20
Rutile	11
Hornblende	10
Tourmaline	8
Muscovite	6
Actinolite	5
Monazite	1

A little garnet and staurolite and other minerals from the rest.

In another specimen (43/194) the heavy residue consisted of very abundant tourmaline with a little magnetite, ilmenite and rutile. In two other specimens (43/182 and 43/184) magnetite and ilmenite form about 50 per cent. and tourmaline 47 per cent. of the heavy residue, the rest being garnet, zircon, rutile, epidote and staurolite.

The above assemblage shows derivation from the tourmaline-rich metamorphics and associated granitic intrusives of the neighbouring regions. The abundant felspar must have been derived from granitic rocks. The presence of jasper pebbles points to the original materials being partly contributed by jasper-bearing rocks like the Iron-ore series in Singhbhum or its former extensions. Even at the present day, the Koel, and through it the Brahmani, show in their beds pebbles of this nature derived from rocks of the Singhbhum district. It can, therefore, be suggested that the gneisses and granites occurring on both sides of the Gondwana strip, as well as the Dharwars occurring on the north-east and their original extensions, have contributed much, if not all, of the sediments which make up the Gondwanas.

Source of sediments.

From near Rattansara south-eastwards the Barakars are composed of a succession of sandstones, shales and carbonaceous shales with intercalated coal seams. Good sections are seen in the Baisundar *nala*, one mile north of Gopalpur. The portion of the Baisundar just above the junction with its tributary shows sandstones and shales lying unconformably over the metamorphics. The mica-schists here, which are penetrated by abundant veins of quartz and pegmatite, dip towards the north or north-east at varying angles, the lowest value being 40°. The Barakars lying above them dip to the south (varying to S. 10° E.) at an angle of 7° to 10°. The basal sandstones are medium- to coarse-grained, and are probably about 100 to 120 ft. thick. These are overlain conformably by carbonaceous shales with intercalations of coal seams. Just at the bottom of the shales is an impersistent band of a few inches thickness, which is of the nature of a finely banded siliceous shale (specimen 43/193: section 21377), which shows very minute folding and crumpling. The coal-bearing shales are 45-50 ft. thick and reach down to the junction of the streams. There are several layers of coal, each having a thickness varying generally between 5 and 10 inches. Plate 7, fig. 2, shows a portion of this coal-bearing section in the Baisundar. The coal seams are of unattractive quality (43/192), being generally composed of layers of durain and fusain. A few thin layers of shining black vitrain, up to a maximum of one inch in thickness, are also seen. The seams are somewhat better in the lower and upper

Section in the Baisundar, north of Gopalpur.

Shale.

Coal.

portions and very poor in the middle portion. In the upper part of the section there is a very conspicuous layer, about 10 to 12 inches thick, composed of a mixture of vitrain and powdery cherry-red ochre (N. 187). Occasionally, the greater part of the thickness of this layer may consist of almost pure ochre (N. 186). Owing to its conspicuous colour, this particular layer can be easily traced from the above locality to a point due south of Tiklipara. Further particulars about this and the coal are given under the economic section.

Vitrain and ochre.

Overlying the coaly shales of this section are sandstones which can be traced southwards. Other outcrops of coal bearing shales are found at several points between Rattansara and Dulanga. The following is a list of those observed by me: –

1. Near Rattansara and for some distance eastwards.
2. Due north of Gopalpur.
3. Near Sardega in the Baisundar and also in a small stream joining it from the north.
4. At several points north and north-east of Siarmal.
5. South of Kirpsera.
6. North of Bankibahal.
7. South of Dulanga.

I had no occasion to see the exposures at Ghogarpali and Bhograkachhar described by Ball. A few thin seams, each 3 to 6 inches thick, were observed by me in the Barakar sandstones in a stream near Bandega (22° 10′ : 83° 39′).

Hingir sandstones.

The Hingir sandstones of Kamthi facies (Raniganj stage) were observed in my traverse from Kanika (Himgir railway station) to Kirpsera. They dip to the west in the area between Kanika and Himgir and south-westwards between Himgir and Kirpsera. They are dull chocolate-brown in colour with occasional layers of creamy to pale red colours. They are generally coarse-grained and contain grit and conglomerate bands. The rocks consist essentially of quartz and limonitic cement. Flakes of mica and some grains of dark iron ore are also present.

Ball and King have shown that the Gondwanas form a basin-shaped structure, in the centre of which the town of Himgir is

situated. Ball[1] obtained the following plant fossils (determined by Feistmantel) from the Hingir sandstones in the Garjanjor hill (△ 1956.—22° 2′ : 83° 40′) :—

Schizoneura gondwanensis, (leaves and stalks).
Vertebraria indica, Royle.
Sphenopteris polymorpha.
Pecopteris sp.
Glossopteris indica, Schimp.
G. browniana (?) Bgt.
G. angustifolia, Bgt. (with marginal line).
G. communis, and another species.

From this assemblage the age was fixed as the Raniganj stage, the lithological characters indicating a Kamthi facies.

The sandstone contains red ochreous clay as a matrix, which is sometimes sufficiently abundant in certain layers to be worth consideration as ochre, for use as paint.

[1] V. Ball, On the Geology of the Mahanadi Basin and its vicinity. *Rec. Geol. Surv. Ind.*, X, pt. 4, p. 171, (1877).

PART II.—ECONOMIC GEOLOGY[1].

CHAPTER XIV.—MANGANESE-ORE.

In the first part of this memoir a general description of the occurrences of manganiferous rocks has been given. The information contained there will be supplemented here with regard to the mining activity, the quarries, nature of the ores and other connected matters.

In 1908, the Geological Survey of India received a specimen containing trapezohedral crystals of garnet and also braunite (K. 454) through Dr. A. W. G. Bleeck, from the Ghoriajor deposit. About the same time, a large specimen of manganese-ore from the same deposit was analysed by V. G. Spiera of Kamthi, with the following result[2].

Analysis of ore dried at 100° C.

	Per cent.
Manganese	51·37
Silica	1·50
Phosphorus	0·072

Mention of manganese ores in the State is made by Sir Lewis Fermor in his memoir[3]. The same author visited the mining operations at Ghoriajor in 1908 and embodied his observations in a paper entitled 'Notes on the Manganese-ore Deposits of Gangpur State, Bengal, and on the Distribution of the Gondite series in India'[4]. The late Mr. E. Vredenburg also visited the area in 1910, but there exists no published account of his observations.

Previous work.

Description of ore occurrences.

From the general description of the distribution of the gondite series, it will be gathered that the ore-bearing areas are confined to these and form only a small portion of them.

[1] It is to be noted that the state of affairs described in this part of the memoir refers to the year 1934 when this was written.—M. S. K.

[2] L. L. Fermor, *Mem. Geol. Surv. Ind.*, XXXVII, p. 615, (1909).

[3] *Mem. Geol. Surv. Ind.*, XXXVII, p. 615, (1909).

[4] *Rec. Geol. Surv. Ind.*, XLI, pp. 12-21, (1911).

Gobira.

At Gobira there is a trench measuring 50 yards by 12 yards. This is of varying depth, the maximum being 20 ft. Apparently some desultory quarrying was done a little over a decade ago, the rather inferior grade granular to powdery ore finding a market at that time. Thin veins of good hard ore (psilomelane with some braunite) are also found in comparatively small quantities in quartz veins or 'reefs'. Most of the ore seems to be pyrolusite with small amounts of psilomelane. All stages of alteration of spessartite to ore can be seen in the quarry.

Ratakhand (Jaidega).

About three miles W. by S. of Gobira, and between the villages of Ratakhand and Jaidega, are two pits which had yielded marketable ore. The larger of these is 40×10 yards and about 15 ft. deep, the length being in a N. N. W.- S. S. E. direction. The second pit is 120 yards to the north of the above, measuring 15 ft.×15 ft.×10 ft. It is nothing more than a prospecting pit, exposing ore of poor quality. The ore is similar to that at Gobira and is seen to be irregularly distributed in streaks and lenses throughout the width of the quarry.

Pandrisila.

The main occurrence here is on a low hillock which adjoins the north-western hamlet of Pandrisila. Another hillock at the eastern end of the above also exposes similar rocks which are much poorer in ore.

In the main outcrop there are three long trenches in the gondite, which have, however, only slightly penetrated the solid rock. The depth is between 10 and 15 feet from the surface of the hillside. Most of the ore won here seems to have been won from the disintegrated veins. There is apparently no ore of marketable quality in the eastern hill.

From the available evidence at present it can be said that the ore was of somewhat better quality than that from the more eastern quarries. That is to say, it shows a greater proportion of psilomelane and less of crumbling and powdery pyrolusite. Some veins of comparatively hard psilomelane and braunite seem also to be

present, out of which some ore of good quality has been quarried. Specimens M. 997 and N. 26 were collected from the trenches here.

Panchra and Kohupani.

A little to the south of Kohupani village (22° 18′ 30″ : 84° 27′) there is a series of five medium-sized pits in the gondites which occupy here an approximate width of 150 ft., and which seem to have yielded second grade ore, judging from the few small ore stacks left near the pits. Further west, along the same strike, are several small pits and trenches near Raidihi, Jhirpani, and Panchra. From all of these a small tonnage of ore has been recovered, all apparently of second grade. These ores are mainly psilomelane and pyrolusite, with occasionally a little braunite. The shallowness of the pits and their large number would point to poor concentration of the ore along this band.

South-west of Kusamdega some small prospecting pits were noticed but apparently no marketable ore has been recovered from here.

Dandjamira.

A little further to the south-west and about one mile due north of Dandjamira (and a quarter of a mile north-west of the northern hamlet of the same village), a quarry of some size is seen which is 200 ft. long, 50 to 60 ft. wide and up to 25 ft. deep. The site seems to have originally formed a small knoll. The ore won here was of better quality than that of the other quarries detailed above and consists of braunite and psilomelane* with a little pyrolusite. The ore bands, so far as could be seen, were comparatively thin, but the dimensions of the quarry show that they were sufficiently rich to warrant continuous operations for some time in a single quarry.

Dhumagarha—Kharkamunda—Raidih.

There is a continuous band of gondite from Dhumagarha through Kharkamunda to Raidih. There is a large but shallow quarry adjoining Dhumagarha village measuring 100 ft.×40 ft.×6 ft., the ore won from which shows braunite, psilomelane and wad, and is generally of a low grade. Between this and Kharkamunda there are several small pits, only three or four of which seem to have yielded any marketable ore. Just west of Kharkamunda again is a large quarry 200 ft. long, 30 ft. wide and up to 25 ft.

deep. From here to the south-west are several small prospecting pits up to the village of Raidih.

In this band the best ore-bearing portion was apparently near Kharkamunda, as the ore from the quarry there was partly of excellent quality, composed of braunite and psilomelane.

Khorla.

The exposures near Khorla do not seem to have yielded any good ore. A few shallow prospecting pits exist. The concentration of the ore is poor and the ore itself is of inferior quality, containing a high percentage of unaltered silicates. In addition to powdery and impure wad, small quantities of psilomelane, braunite and vredenburgite were noticed here.

It has been mentioned that the south-western exposure is surrounded by coarse granite. The granite seems to have had no effect on the ore.

Nakti.

There are a number of small outcrops in the neighbourhood of Nakti (22° 7′ : 84° 13′), *Ghantbur and Lahandabur.* All these have been pitted and some good ore has been recovered. The veins are comparatively thinner and less persistent here than those further south-west in Ghoriajor, but are better than most of the occurrences further to the north-east. The largest of the pits are near Nakti and from these good ore of the first grade is said to have been quarried. None of the pits or trenches exceeds 20 ft. in depth, the average being 10-12 ft.

Ghoriajor - Manomunda group.

This forms the south-westernmost group of the outcrops of the State, and are by far the most important in extent and richness. Ghoriajor is about seven miles from the Dharuadihi station on the Bengal Nagpur Railway and connected with it by a cart-road, which proceeds to Sundargarh which is some eleven miles further on. Recently (in 1932) a new motor-road has been opened which goes straight west from Ghoriajor and joins the Sundargarh-Jharsuguda road near Kurai, some three miles south of Sundargarh.

The manganiferous rocks were originally exposed here in hillocks which have since mostly disappeared through quarrying operations,

The quarries fall into two divisions, one grouped around Manomunda (the Kumtimunda or Birbira quarries of Sir Lewis Fermor) and the other around Ghoriajor.

The Manomunda group is nearly due west of the Kumtimunda village. There are about six large quarries here and several smaller ones, all of them at present being full of water. The larger quarries have received the following names :-

Lohargarha (*Mohalgarha*).
Tetulgarha.
Baladgarha.
Kusumgarha.

The general disposition of the different quarries is shown in the following diagrammatic sketch made by Mr. D. P. Chandoke, while he was working with me in this area in the year 1931.

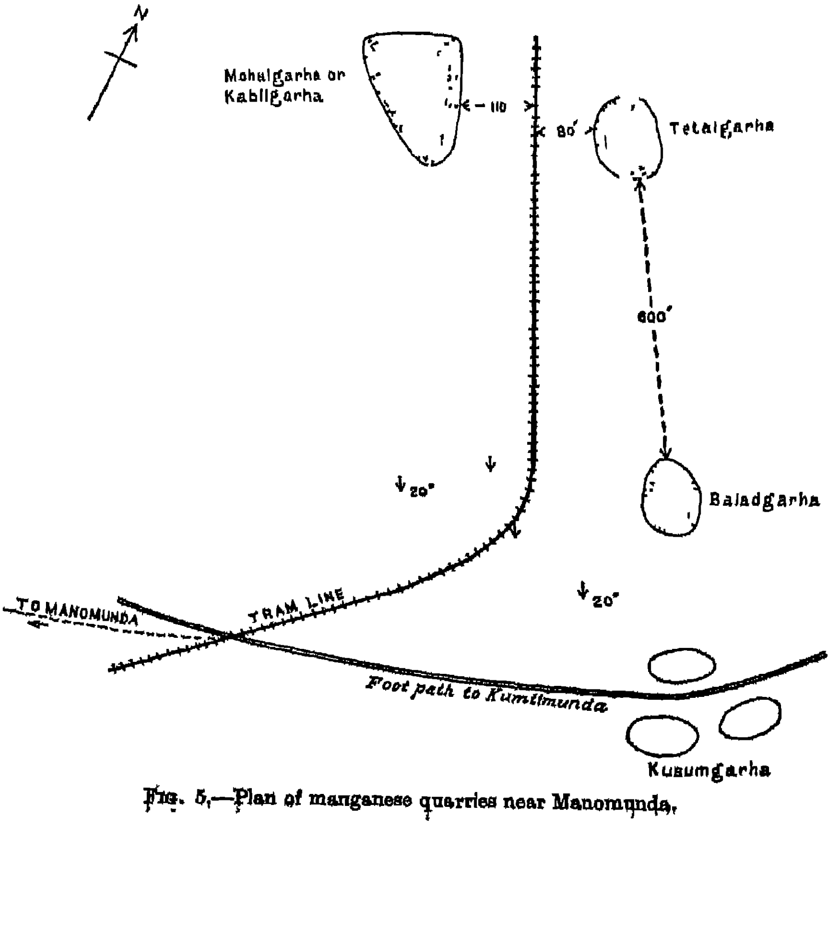

FIG. 5.—Plan of manganese quarries near Manomunda.

The *Mohalgarha* (or *Lohargarha*) is the northernmost of the group, except for some small prospecting pits lying to its north-east. At the time of Sir Lewis Fermor's visit in 1908 a considerable amount of excavation had been done here. It is now a large pit roughly triangular in plan, the two sides which form a right angle being 150 ft. and 250 ft. respectively.

The depth increases from nothing on the western side to about 25 ft. near the eastern. There is a trench within this, parallel and close to the eastern side, and this is some 15 ft. deeper than the general level of the adjoining portion of the quarry. From information gathered from the miners and foremen who were formerly working here, it appears that in the trench itself and in its immediate neighbourhood, there are fairly persistent and rich veins of manganese-ore in gondite, one of the veins being as much as four feet thick. At the time of abandoning the quarry, by the New Gangpur Syndicate in 1927, the veins in the trench were yielding excellent ore. At the northern end of the *Mohalgarha* is a small pit which is about 25-30 ft. below the ground-level around. This shows highly folded quartzites, gondite and schists. (*see* Plate 8, fig. 2.)

In the somewhat high ground to the north-east of the same quarry, some pits were put down in gondite by the Orient Mining Syndicate in 1929, revealing thin impersistent veins of ore. As the indications of ore were not promising, further exploration was not proceeded with.

The *Tetulgarha*, situated about 300 ft. east of the southern edge of the *Mohalgarha*, is a quarry measuring 250 ft. by 100 ft., with a maximum depth of some 35 ft. This seems to mark the site of the hillock mentioned by Sir Lewis Fermor as being 300 yards E. by S. of the main working, wherein gondite bands containing ore were being opened up in 1908.

The relative positions of the *Baladgarha* and *Kusumgarha* and their dimensions are given in the sketch. They are on an average 25-30 ft. in depth. Towards the close of the mining operations here, the New Gangpur Mining Syndicate seem to have left the contractors to win the ore to the best of their ability, the result being that veins have been followed down in a series of irregular burrowings into the rock.

Six or seven smaller pits are present near the village of Manomunda and adjoining the path connecting it and Kumtimunda. Some of them still expose veins between 6 inches and 18 inches

thick. They also are comparatively shallow. In the area intervening between the last mentioned quarries and the *Shrager Hill* quarry near Ghoriajor, there are small prospecting pits in all the gondite exposures and along their general strike, but no ore-veins of any importance have been found.

Ghoriajor group.

The most prominent of this group are two quarries which lie end-on, along the strike of the rocks, just to the south of the cart-road. The bigger, north-eastern one is called the *Baragarha* and the smaller, south-western one the *Semulgarha*. The two are separated by a transverse wall of some 25 ft. thickness. The *Baragarha* is nearly 120 yards × 100 yards and the *Semulgarha* 100 yards × 70 yards. Both are filled with water. The depth of the *Baragarha*[1] is said to be nearly 150 ft. below the level of the surrounding ground and that of its companion only about 70-80 ft. The ends of the quarries which are across the strike direction and also the south-east side are steep and hence difficult of access, and not available for close examination. The north-west side exposes phyllites with occasional quartz and pegmatite veins.

Sir Lewis Fermor[2] has recorded that these main workings originally formed a hill 70-80 ft. above the surrounding country, the length of exposure of ore being some 720 ft. on this hillock. The hill was highest near the north-eastern end, gradually diminishing in height towards the south-west. The ore band was 10-20 ft. thick at its maximum, but owing to the increase of the thickness by folding it appeared in places to be 50 ft. or more in thickness. (*See* figure 2.)

The dip of the beds, with which the ore bands are conformable, is about 40° near the surface. It is learnt however that at depth the ore showed steeper dips. A stage was reached when, for the continuance of working, underground mining methods should have been undertaken. Since, with the falling price of the ore and the necessity for the introduction of underground mining, the

[1] I am indebted to Mr. Christian for obtaining first-hand information on this point from Mr. R. Mellon, who was formerly the Superintendent of the Ghoriajor mines. Mr. Mellon writes: 'The floor of the large quarry at Ghoriajor reached a depth of 145 feet, and was in black quartzite; from that level several shafts were sunk to a depth of 35 feet, and still in black quartzite.'

[2] *Rec. Geol. Surv. Ind.*, XLI, p. 16, (1911).

prospects of economic exploitation seemed poor, the Syndicate decided in 1926 to close down the quarries and surrender the lease to the State.

Prichard's Hill.

Some 350 yards to the west of the above quarries is the *Prichard Hill* quarry. This is about 350 ft. long in an E.N.E.-W.S.W. direction, 60 ft. wide and 30 ft. deep. On the northern face of the quarry are exposed gondite and rhodonite-spessartite-quartz rocks. The ore-bearing portion of the gondite is said to have been about 30 ft. thick, the ore bands being as usual a series of lenses. This was also originally a hillock, as the name will show, but is now below the general ground level. Sir Lewis Fermor has recorded four workings within the limits of the Kendmal village, three of these being in low ridges west of the south-western end of the Ghoriajor hill. These together seem to be the Prichard Hill quarry. The fourth was about 1,100 ft. to the south-west of the Ghoriajor hill, being apparently an extension of it.

There are several pits and trenches between Amasdegi, Ghoriajor and Birjaberna, *i.e.*, south-west of the quarries described above. They are of various dimensions but the depth is in general between 10 and 20 feet. The northernmost of these is 80 ft. by 70 ft. and 20 ft. deep. The ore-bodies found in these are of different thicknesses and impersistent, and none seems to have exceeded two feet in thickness.

The southernmost of the quarries is about three-fourths of a mile south-west of Birjaberna and two miles north of Kinjirma. It is a shallow quarry, being 100 ft. by 80 ft., with a maximum depth of 15 ft. The superficial material is lateritoid. The gondite exposed in the quarry is a highly quartzose rock containing a few thin bands (one to three inches thick) of rich ore, the general ore-material being of poor quality.

Shrager Hill.

Another important member of this group is the one called the *Shrager Hill* quarry. This is described by Sir Lewis Fermor as the Ghoriajor north-east workings, situated on a low ridge about 2,000 ft. to the north-east of the eastern end of the Ghoriajor hill. The original knoll here exposed four main ore 'reefs' which were

followed down, the lowest one being 30 inches, and the upper ones between 6 and 18 inches, in thickness. This knoll was by the side of a stream course, and was quarried only to a depth of about 8 to 10 ft. below the level of the adjoining rice-fields. The ore bands proved to be thin and impersistent and there was no improvement below. Moreover, owing to the proximity of the stream course, there was much inrush of water even at the shallow depth, and work was therefore not continued in this quarry by the New Gangpur Mining Syndicate. When abandoned by them the quarry was 150 ft. × 60 ft. (length in a N.E.-S.W. direction) and some 10 ft. deep, one face of the quarry being high ground.

The Orient Mining Syndicate enlarged this quarry both along the directions of dip and rise during the years 1930-1932. When the water was pumped out and the accumulated silt removed, several veins were exposed and these were worked in a small way for about two years till 1932; but the market prices proved to be so unremunerative that work was suspended. A sketch plan of the quarry, drawn by Mr. D. P. Chandoke in 1931, is shown below.

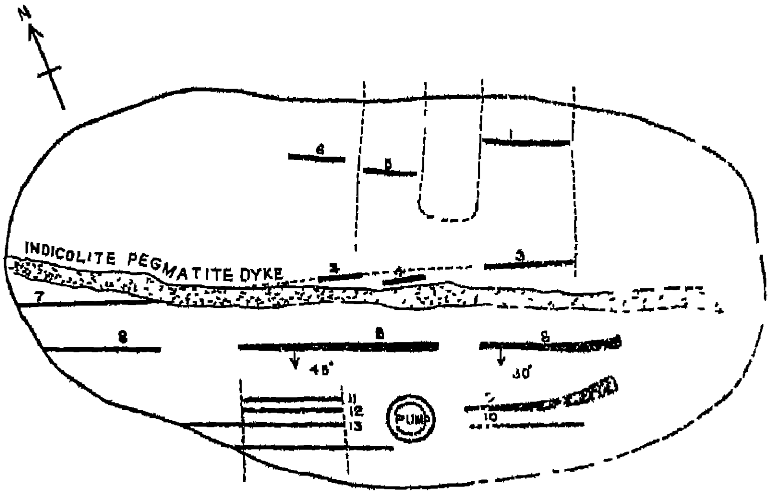

FIG. 6.—Plan of manganese-ore bands at Shrager Hill quarry (in February, 1931).

The centre of the quarry attained, in the summer of 1931, a maximum depth of 35-40 ft. below the northern brow. The southern brow was about 20 ft. below the level of the northern. The thickness of the veins varied from one inch to as much as 30 inches in

one case. Most of the veins show variation in thickness both along strike and dip.

The Orient Mining Syndicate began working the *Shrager Hill* quarry late in 1929. Practically no ore was won in that year. As the quarry was deepened, some of the veins which originally cropped out in the quarry disappeared, but this was compensated for by new ones which appeared below. The northern side of the quarry was also opened up somewhat, since veins were encountered in that direction when broadening the quarry. A good deal of water percolated in at all times, but the intermittent working of a 3½ H. P. oil-engine was able to pump out the water. The quarry was worked only from 1929 to 1932, at a very small margin of profit, and in the latter year the ruling prices proved unremunerative even with the most economical working. All the work—removal of over-burden, breaking up of the ground, picking and dressing of ore—was done by exceptionally cheap labour which cost only 4 to 6 annas per man and 2 to 4 annas per woman per working day.

Lateritoid ore.

To the north-west of the Ghoriajor quarries, between them and the village of Kendmal, as well as near Amasdegi, are areas showing a superficial lateritoid material. To the east of Kendmal village, on both sides of the new motor-road, there is an area of about 500 yards by 250 yards which is honey-combed by shallow pits. Here as well as near Birjaberna and Amasdegi, the surface shows lateritoid gravel which, when broken up, has yielded some quantity of lateritoid ore consisting essentially of limonite, psilomelane, pyrolusite and wad. The pits nowhere exceed 10 or 12 feet in depth, and from all accounts, were not worth deepening even in the most prosperous days of the manganese market. The lateritoid ore passes into lateritic gravel and vermicular laterite on the one hand and partly altered gondite on the other.

The ore occurs as nodules and pockets in the lateritoid rock from which it used to be dug up and hand-sorted. The distribution is very irregular and the deposit as a whole is of little economic value.

Nature and quality of the ore.

By far the largest part of the ore won and shipped from Gangpur State consisted of braunite and psilomelane, mainly derived from the Ghoriajor-Manomunda group. In the cavities of the ore a small amount of powdery pyrolusite is often present. The ores from the other quarries seem to have been of lower grade, consisting of crumbling masses containing wad, psilomelane, pyrolusite and some braunite. As will be seen from the table of production, the lesser quarries produced only a small tonnage in comparison with the Ghoriajor-Manomunda quarries. Small quantities of ore are to be seen now in the stacks at the different quarries and they give an idea of their nature. In addition to the minerals noted above, a little vredenburgite, hollandite and manganite have also been noticed in the ore. Mangan-magnetite was suspected to be present by Sir Lewis Fermor, but I have not been able to identify the mineral definitely in the ores here. The last named minerals are quantitatively of no importance whatever, being no more than mere curiosities.

In his paper on the Ghoriajor deposits, Sir Lewis Fermor has given some analyses[1] of the ores which are reproduced below:

TABLE 10.—*Five hand-specimens of Ghoriajor ores analysed by Messrs. Pattison and Stead.*

—	1	2	3	4	5
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Manganese . . .	55·35	58·64	55·84	45·48	50·71
Iron	3·60	1·70	1·98	16·33	4·15
Silica	3·03	1·18	0·90	0·65	2·10
Phosphorus . . .	0·089	0·079	0·132	0·141	0·110

1. Banded, slaty, hard braunite-psilomelane ore, very fine-grained.
2. Rather coarse-grained, hard braunite-psilomelane ore.
3. Banded braunite-psilomelane ore with the psilomelane predominant, and a large number of tiny black specks making the ore somewhat vesicular.
4. Soft, crystalline ore, with some of the hard grey braunite-psilomelane ore in the middle.
5. Concentric-banded psilomelane (lead-like), with soft black ore.

[1] L. L. Fermor, *Rec. Geol. Surv. Ind.*, XLI, p. 14, (1911).

TABLE 11.—*Samples of Ghoriajor and Birbira (Manomunda) ores, analysed by G. M. Prichard.*

——	1	2	3	4	5
	Per cent.	Per cent.	Per cent	Per cent.	Per cent.
Manganese	51·81	49·44	50·03	50·80	45·34
Iron	6·38	..	..	..	..
Silica	3·52	10·65	..	..	11·75
Phosphorus	0·09	0·068	0·041	0·057	0·078

1. 200 tons of Ghoriajor ore.
2. 515 tons of ore Manomunda quarries.
3. Same as No. 2, after picking at the station.
4. About 40 tons of stacked 'boulder' ore (nodular superficial ore).
5. Six stacks of bed-ore (from veins or reefs), south of No. 1 hill.

The following range of analyses of 53 cargoes, aggregating to 30,170 tons, shipped from the area in 1909 is also given by Sir Lewis Fermor.

TABLE 12.—*Range and mean of analyses of 53 cargoes of manganese ore from the Ghoriajor area.*

——	Range.	Mean.
	Per cent.	Per cent.
Manganese	45·58 to 54·13	49·31
Iron (54 anal.)	2·60 to 7·92	6·59
Silica	2·60 to 11·20	4·41
Phosphorus (51 anal.)	0·061 to 0·150	0·117

The following analyses of ore from Shrager hill and from a pit in Ghantbur were kindly supplied to me by Dr. M. Patel of the Orient Mining Syndicate.

TABLE 13.—*Analyses of ore from Shrager Hill, Mohalgarha, and Ghantbur quarries, analysed by Messrs. R. V. Briggs & Co.*

——	1	2	3	4	5	6	7
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Mn	48·1	50·3	48·3	48·8	48·7	49·0	49·0
Fe	0·40	5·21	7·6	9·60	9·06	8·28	8·3
SiO_2	15·48	4·16	5·61	8·11	6·70	6·70	6·83
P	0·081	0·130	0·098	0·101	0·108	0·096	0·086

1. Mohalgarha—sample from an ore stack; Apl. 1930.
2. Ghantbur—ore from a new pit; Apl. 1930.
3. Shrager Hill—Bulk sample, 110 tons; Apl. 1931.
4. „ „ „ „ 375 tons; Apl. 1931.
5. „ „ „ „ 500 tons; Nov. 1930.
6. „ „ „ „ 450 tons; Apl. 1931.
7. „ „ „ „ 540 tons; June 1931.

Comparison of tables 10 and 13 shows that the ores from Shrager Hill are poorer in manganese and richer in iron and silica than the general run of ore from the Ghoriajor quarries but are comparable to the Manomunda (Birbira) ores. It should, however, be pointed out that the samples in Table 10 were picked hand-specimens, which may be expected to have been purer than bulk samples.

In the following table are given the range and mean values of analyses, as given by Sir Lewis Fermor[1], of Indian ores shipped to England in the early years of the present century. This may be compared with Table 12. For further particulars Sir Lewis Fermor's memoir (pp. 501-514 and 517-521) may be consulted.

TABLE 14.—*Analyses of Indian manganese ores.*

——	Central Provinces and possibly Jhabua and Panch Mahals.		Vizagapatam.	
	Range.	Mean.	Range.	Mean.
Mn	47·25 —54·53	51·31	42·13 —47·53	45·95
Fe	3·85 — 7·98	5·53	9·14 —11·69	10·20
SiO_2	3·33 — 9·99	6·13	2·63 — 3·66	3·10
P	0·056— 0·163	0·096	0·235— 0·331	0·291
Moisture . . .	0·21 — 2·64	0·71	0·64 — 0·95	0·76

[1] *Mem. Geol. Surv. Ind.*, XXXVII, p. 519, (1909).

I have been unable to obtain any analyses of ores from the quarries in other parts of Gangpur, but they are doubtless of a lower grade than the ores from the Ghoriajor group of quarries.

Lateritoid ore.

This type, often called 'boulder ore' here, as already remarked, is of a friable nature and of a poorer quality than the massive bedded or 'reef' ore. It occurs in the form of small 'boulders', nodules or lumps in lateritic material. The range of analyses of some ores which were collected from the Kendmal area, kindly supplied by Dr. M. Patel, is given in the following table, together with values for similar ores from other areas taken from Sir Lewis Fermor's memoir (p. 389).

TABLE 15.—*Range of analyses of lateritoid manganese ores.*

—	Gangpur.	Belgaum.	Shimoga.		Sandur.
			High grade.	Low grade.	
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Manganese . .	11 17	31·2 —60·8	41—50	30—38	30·47 —54·30
Iron . . .	5- 10	0 1 - -18·1	2 10	10 —20	5·38 —19·40
Silica . . .	2 1	0·6 — 2·5	1- -3	2—6	0·13 — 1·00
Phosphorus . .	..	0 01— 0·12	0·015 0·06	0·01—0·6	0·010— 0·033

History of development.

The occurrence of manganese-ore in Gangpur State seems to have come to prominence only in 1907 through the prospecting work carried out by Mr. Isaac Shrager on behalf of Babu Madhu Lall Doogar. In August of that year, a prospecting licence for manganese over an area of 96 square miles was granted to Mr. Doogar by the then Ruling Chief of Gangpur. In 1909, Mr. Doogar was joined by Messrs. I. Shrager and Bhupendra Nath Basu as partners. A light tramway from Dharuadihi railway station to Ghoriajor was built in the year 1908 by the Gangpur Light Tramway Co., Ltd., under the management of Messrs. Grossman & Co. and opened in January of 1909. An account of this was published in the Indian

and Eastern Engineer.[1] A mining lease was granted in 1912 over an area of 7·25 sq. miles, but as the State authorities found that the deposits were not properly worked, the lessees were evicted. This led to an appeal by the lessees to the Secretary of State for India, who however upheld the eviction. The lease therefore lapsed in 1914.

A second lease was granted in 1917 to the New Gangpur Mining Syndicate with Mr. (now Sir) M. B. Dadabhoy and others as partners. By about 1927, the veins had been followed to some depth below the surface, and quarrying became costly, simultaneous with falling market prices. This Syndicate therefore decided to stop work in 1927 and surrendered the mining rights to the State in the following year.

A prospecting licence for the Ghoriajor area was taken out by Dr. M. Patel and partners under the name of Orient Mining Syndicate in 1929. This concern worked the Shrager Hill quarry on a small scale but found it difficult to carry on under the conditions of the prevailing manganese market. They had virtually ceased to work in 1932.

The new Gangpur Mining Syndicate also worked some quarries at Nakti and Ghantbur lying to the north-east of the Manomunda quarries.

During the War, in 1916, Messrs. B. P. Byramjee & Co. took up prospecting licences over the other areas in the State. A mining lease over an aggregate area of 0·618 sq. miles was taken up in 1918, comprising plots in Salebira, Raidih, Kharkamunda, Dhumagarha, Dandjamira, Kusamdega, Jhirpani and Panchra. Another area, aggregating to 0·77 sq. miles, and including Pandrisila and Gobira, was leased out to the same company in 1921. Both the above leases were surrendered in 1930-31 but no work had been done in any of the quarries since 1925.

So far as known, there was no production of manganese-ore in 1934 or later.

Production and prospects.

In the accompanying table (Table 16) are given the figures of production of manganese-ore from the different quarries in the State. The figures published annually and quinquennially by the Geological

[1] *Ind. Eastern Eng.*, XXVI, pp. 96-98, (1910).

TABLE 16.—*Production and value of Manganese-ore in Gangpur State.*

—		1907.	1908.	1909.	1910.	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.
N. G. M. S.— Ghorlajor	Tons	2,000	18,942	43,877	41,958	25,152	27,113	11.215	6,070	..	..	6,780	11.295
Birbira	,,	..	3,000	?	..	..	..	..	..	..	..	..	..
B. P. B. Co.	,,	..	..	..	..	..	..	..	..	..	2,882	5,000	4.600
TOTAL	Tons	2 000	16 942	55,060	41,958	25,152	27.113	11.215	6,070	..	2,882	11,780	15,895
Pit's mouth value	Rs.	..	..	110.121	..	..	90,754	..	36,420	..	3,908	94,020	181,702
F.o.b. Indian Ports	£	3,417	18.424	54.142	41.259	25.257	37,476	16.168	7,613	..	6,018	27,290	41,327

—		1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933
Ghorlajor	Tons	12,616	12,889	13 897	10.061	12,086	10.267	5,734	7,062	6 765	6.379		..	..	..	..
Shrager Hill	,,	2,872	2.797	1,555	1,762	1,986	2,017	475	213	..	..		486	793	1,110	1,052
Birbira	,,	4,948	4 930	4.371	4,848	4.873	3,229	2 684	2,808	1.195	..		..	..	..	..
Kakti	,,	37	..	..	..	674	963	594	281	..	..		..	..	..	..
Gobira	,,	234	..	..	..	40	..	..								
Pandrisila	,,	501	..	..	111	416	..	..								
Jhirpani	,,	..	37	..	..	81	..	..				No production.				
Uparbahal	,,	..	..	..	23	66	..	25								
Panchra	,,	..	274	..	46	198	..	33								
Dandjamira	,,	..	234	..	18	..	..	1								
Dhumagarha	,,	..	..	..	3	69	..	38								
Kharkamunda	,,	..	..	..	..	..	..	33								
TOTAL	,,	21,208	21.161	19,823	16.372	20,439	16.481	9,617	10,379	7,960	6 379		486	793	1,110	1,052
Pit's mouth value	Rs.	260,280	180,221	250 015	201.771	217,769	309.018	228 733	249,096	183 080	132,826	..	..	..	..	..
F.o.b. Indian Ports	£	57,262	108,865	45,427	82,062	67,619	57.184	30,834	26.856	20,928	16,154		..	..	..	..

Survey of India have been checked against those obtained direct from the State through the courtesy of Mr. H. D. Christian, Superintendent of Gangpur.

There was no production in 1915 and 1929 for the reasons already stated. Some desultory quarrying has been going on since 1930, but even this has been stopped by the end of 1932. The total production to date amounts to nearly 370,000 tons, of which by far the largest part has come from the Ghoriajor group of quarries.

From the information gathered locally, it appears that the main reason for the New Gangpur Mining Syndicate closing down the manganese quarries was the increase of working depth and of cost of production, when simultaneously the prices were falling steadily to an unremunerative level. All the quarries were producing up to the last, and so far as known, there was at no time any difficulty in finding ore. Even in the Ghoriajor main quarries, where the veins were thickest, these continued at depth without any serious thinning or lowering of the quality. The veins had however changed their dip to a steeper angle and the cost of quarrying had increased.

The Syndicate seem to have decided on closing down their operations in 1925 or 1926, and by the end of 1927 had disposed of most of their stocks. In the same year their activities were transferred to their properties in the Central Provinces, and several hundred labourers used to manganese mining also migrated. But with the setting in of the industrial and financial depression, the mining activities in the Central Provinces had also to be curtailed.

There is no doubt that a large quantity of high grade ore still remains within workable depths in the Ghoriajor-Manomunda area. But sooner or later underground mining will have to be resorted to, since much of the ore within 30 to 40 feet from the surface had been quarried. Even now, opencast quarrying can be carried on in all except the two large quarries at Ghoriajor. Under the present conditions, however, the working of even the richest of the ore bodies is an uneconomic proposition, for the ruling prices are below the cost of production and freight charges to the seaport.*

It will be evident therefore that it is not the paucity of the ore within workable depths, but the present uneconomic price level

* This paper was written in the latter part of 1934 and submitted for publication early in 1935. Though these remarks apply strictly to that period, the improvement which has since taken place in the mineral market does not yet warrant any optimism as to the resumption of mining activity in this area.

prevalent in the manganese market, that is responsible for the absence of mining activity in Gangpur State in respect of manganese-ore.

The other quarries of the State, which contain only lower grade ore, can be re-opened only when specially favourable conditions obtain, as did during and immediately after the War. A large tonnage of second grade ore undoubtedly exists in all the areas of manganese-bearing rocks in the State, but they must remain unworked until a demand for such ore can be stimulated or until some process of beneficiation can be applied to them with success.

CHAPTER XV.—LIMESTONE AND DOLOMITE.

History.

The earliest published reference to limestone in Gangpur State is that of V. Ball[1] who wrote:—

'The last section in this tract of country which there is space to notice here is that afforded by the (Gangpur) Sampai,[2] a tributary of the Ebe. Close to Kujerma (Kinjirma) the bed of the river discloses a thickness of 50 to 60 ft. of blue limestone, dip 40° south-south-east. Underneath these are somewhat sandy quartzites, and the two rocks taken together are not unlike the Vindhyans seen near Padampur .... A portion of the limestone is of inferior quality, containing tremolite; but much of it is a strong pure rock, which ought to prove valuable should occasion arise for its employment.

The same limestone is seen near the junction of the Sampai with the Ebe, where it occurs in horizontal beds, abutting against a vein of coarse granite.'

The commercial exploitation of the limestone and dolomite however was started at the other end of the State, near Rourkela and Bisra. In February, 1898, Mr. E. G. Barton was granted a lease to quarry limestone in an area covering 12 acres near Jugdah, Banposh and to the north of Rourkela. He took up a further lease of 23 acres in 1902, in the following localities: Jhirpani north-east of Rourkela, Khatangkudar, Ursu and Makankudar (which is probably Masrikudar), which are further east.

Mr. Barton, however, transferred the above leases to Mr. Zobel who formed the Bisra Co., with Messrs. F. W. Heilgers and Co. of Calcutta as managing agents. Mr. Zobel took prospecting licenses for certain additional areas in 1903, and a mining lease over a total area of 2,317 acres in March, 1910. The plots comprised in this lease were:—

Name of Lease.	Area in acres.	Location.
H	40	Jaraikela (near Singhbhum boundary).
I	40	Kondra (on the Deo river).
J	40	Satra (N. W. of I).
*K	225	Gutitangar (Amghat).
*L	40	Laingar (Near Amghat).

[1] V. Ball, On the Geology of the Mahanadi basin and its vicinity. *Rec. Geol. Surv. Ind.*, X, p. 182, (1877).

[2] Though *Sampai* is the correct spelling, or rather transliteration, *Sapai* is found on modern maps, and has been used in the present Memoir.

Name of Lease.	Area in acres.	Location.
*M	65	Bhalupatra and Chikatmati (Near Kalunga).
*N	50	Kumarmunda (3¼ miles N. E. of Kalunga).
*O	200	Banposh (N. of Panposh).
*P	50	Lunkera (N. of Panposh).
Q	50	Hamirpur (N. of Rourkela).
R	65	Jhirpani (N. E. of Rourkela).
S	200	Jagdah (E. of R).
T	50	Bangurkela (N. W. of Bisra).
U	250	Khatangkudar (N. of Bisra).
V	80	Tetarkera (adjoining U).
W	400	Ursu and Masrikudar.
X	207	Bisra } adjoining railway stations for building and storage.
Y	180	Rourkela
*Z	25	Kalunga

Of the above, those marked with an asterisk (total of 715 acres) were transferred to the Tata Iron and Steel Co., and the others to the *Bisra* Stone Lime Co., in 1911. The latter took further leases, a few years later, over a total area of 6,400 acres, comprising the following :—

Area in acres.	*Location.*
140	Sarasbuni (on the Sapai, N. W. of Dharuadihi).
192	Amasranga-Bandubahal (on the Sapai, N. W. of Dharuadihi).
153	Kaduapara (N. of Garpos).
192	Purkapali (N. of Garpos).
108	Tunmura and Kukarbhuka (N. W. of Sonakhan).
96	Katang (N. W. of Sonakhan).
179	Khatkurbahal (N. of Katang).
2,746	Lanjiberna eastwards to Kisramal.
26	Khairdih (Near Hetpos).
245	Raiboga.
1,972	Raipura-Banki (Birmitrapur).
141	Purnapani (near Hathibari).
480	Gatitangar (E. of Hathibari).

The Bisra Stone Lime Co. transferred the last two items of the above to the Indian Iron and Steel Co., Ltd., in 1919, but the latter have not found it convenient to work those. The Katang lease, in which limestone was quarried for some time, was proposed to be sold to the Eastern Iron Co. (Villiers and Co.) but before the sale was effected, the buyer company went into liquidation, and the transaction fell through.

Only a few small areas are held on lease by others unconnected with the Bisra Stone Lime Co. These are:—

(i) Tunmara-Gamhardih (Jharbera), and Khatkurbahal, held by the Tata Iron and Steel Co., the areas being 119 and 423 acres respectively. The former is just south of Kukarbhuka and the latter north of Katang. The prospecting licence was granted in 1920 and mining lease in 1923. But the properties have remained unworked.

(ii) Usra (for dolomite), one sq. mile in area held on lease by Messrs. B. P. Byramjee and Co. since November, 1921.

(iii) (a) Hetpos-Jharbera-Dublabera, 295 acres in extent and (b) Lilaikhaman, 130 acres in extent, both leased to the Gangpur Stone Lime Co. (Messrs. B. K. Sanyal, Bholanath Barhi and Co.) in September, 1925.

(iv) A small area at Barpali village (south of Amghat) held by Mr. Jairam Valjee on prospecting licence.

It will thus be seen that the Bisra Stone Lime Co. and the Tata Iron and Steel Co.* between them hold by far the largest part of the limestone and dolomite area in the State. Up to about 1922 the headquarters of the Bisra Stone Lime Co. were at Bisra on the Bengal Nagpur Railway, where they had constructed large lime-kilns, the lime manufactured in which became well known in Calcutta as 'Bisra lime'. In that year, the scene of the activities shifted to Raipura (whose name has recently been changed to Birmitrapur) where the limestones and dolomites are found in enormous quantities and are easily worked. The company have been working there continuously since then.

Transport facilities.

The Bisra Stone Lime Co. constructed a broad-gauge siding extending from that of the Bengal Nagpur Railway which had reached Banposh north-west of Rourkela, to their quarries at Birmitrapur. This line was purchased later by the B. N. Ry. The Birmitrapur-Rourkela section of the Railway had been open to goods traffic since the Railway Company bought the line, but since the last four years or so it has also been opened to passenger traffic.

When the Indian Iron and Steel Co. acquired the lease of Gatitangar and Purnapani areas, the extension of the railway to those

* Tata's have now taken up a lease of the dolomite area at and near Lifripara.—M. S. K.

places was arranged. But, after the partial construction of the earthwork for the track, the scheme was abandoned as the Company decided not to work their property.

The Tata Iron and Steel Co. constructed a broad-gauge siding (assisted by the B. N. Ry.) from Kansbahal station to their Amghat deposits. This line was also later on taken over by the Railway Company.

Light tramways had been used in the case of the other quarries which were worked in the State. The Bisra Stone Lime Company had tramways connecting (1) Sonakhan and Katang, (2) Bisra and Ursu, (3) Bisra and Khatangkudar and Bangurkela, and (4) Rourkela and Jhirpani and Jagdah. These were in use till about 1922, when the Company transferred their activities to Birmitrapur.

Messrs. B. P. Byramjee and Co. have a light tramway between Kulunga station and Usra. As this passes over the Sankh river, a temporary bridge used to be constructed over the river every year just after the monsoon and taken up again before the next monsoon.

A light tramway from Kumarmunda (on the Rourkela Birmitrapur line) to the Dublabera area was constructed by the Gangpur Stone Lime Co. in 1928. It still exists, though the Dublabera quarries have not been worked systematically.

Description of quarries.

The distribution of the calcitic and dolomitic marbles can be gathered from the accompanying map. The calcitic marbles overlie the dolomitic ones and are also more resistant to weathering.

All the important outcrops have been tested by interested parties with a view to their commercial exploitation. Since 1900, quarrying has been done in some area or other, but at present the only outcrop which is worked is that of Birmitrapur, all the others having been closed in recent years owing to various reasons.

Limestone and dolomite have been quarried at different periods at the following places :—

Ursu (22° 17′ 30″ : 85° 1′).
Khatangkudar (22° 17′ : 84° 59′ 30″).
Bangurkela (22° 16′ 30″ : 84° 57′ 30″).
Jagdah (22° 16′ : 84° 55′).
Banposh (22° 15′ : 84° 48′).
Beldih-Chikatmati (22° 15′ : 84° 45′).

Usra (22° 14′ 15″ : 81° 42′).
Amghat (22° 15′ : 81° 37′).
Barpali (22° 14′ : 84° 38′).
Katang (22° 14′ 30″ : 84° 29′ 30″).
Kukarbhuka (22° 12′ : 84° 29′ 30″).
Jharbera-Dublabera (22° 18′ : 84° 38′).
Birmitrapur (22° 24′ : 84° 41′).

The quarries in the outcrops near Bisra have been abandoned 15 years or so ago, while the Katang, Amghat, and Banposh quarries stopped work comparatively recently. The most active period of mining was between 1920 and 1930, as a glance at the production figures will show.

Banposh.

The quarry at Banposh was worked by the Tata Iron and Steel Co. between 1911 and 1927. Practically the whole width of the outcrop has been opened up. It had been closed down by the time my work commenced in the State. A little sporadic quarrying of limestone on the bank of the Koel river just west of the quarry was being done in 1928, but this was more on the scale of exploratory work than regular quarrying. The production from here consisted almost entirely of dolomite. The quarry seems to have reached a maximum depth of 180 ft. In 1933, however, quarrying of dolomite has been started on the bank of the Koel near Banposh.

Usra.

The dolomite band here was exploited by Messers. B. P. Byramjee and Co. At the time of my visit in 1928, the quarry was 800 ft. by 120 ft., and 60 ft. deep, and situated close to the northern bank of the Sankh river. Except for a few, thin, intercalated beds, the dolomite here was of a quality good enough to be used in smelting

The quarry was in operation during the years 1919 to 1930, practically all the production going to the smelting furnaces of the Tata Iron and Steel Co.

Amghat.

There are quarries here both in limestone and in dolomite which were worked by the Tata Iron and Steel Co. The total

exposure is over 2,000 ft. wide, a little less than a third of it being limestone. The two dolomite quarries here, which are said to have reached a depth of 100-120 ft., were closed down in 1926. Early in 1928, when I visited the area, the limestone quarry was working, but that has also been closed down later in that year.

The dolomite quarries, though filled up with water, were being looked after, so that they could be started again at short notice, as the tramline down the incline, the hoisting and loading machinery were all kept in position.

The limestone quarry was about 700 ft. long, 120 ft. broad, and 70-90 ft. deep. The dip of the limestone is very steep towards the north, the top of the northern wall being dolomite. Certain parts of the beds were left out during working and only those which were sufficiently pure for metallurgical purposes were being quarried. A tramline leads down into the quarry down the eastern end, for hoisting the limestone. The material is brought to the loading platform above and loaded direct into railway waggons on the siding of the B. N. Ry. at Amghat, and thence shipped to Tatanagar *viâ* Kansbahal station.

Dolomite quarrying in the Gangpur State has practically ceased now mainly because the Tata Iron and Steel Co. have replaced dolomite by limestone in their blast furnaces. The reason for their closing down the quarrying operations for limestone at Amghat is said to be the increase in the insoluble constituents of the limestone as quarrying was proceeded with at depth. Perhaps an equally valid reason was that it was cheaper to buy from the Bisra Stone Lime Co. than to operate their own quarries at increasing depth.

Barpali.

At Barpali, a little to the south-east of Amghat, there is a quarry in limestone measuring 60 ft. × 60 ft., and 10-15 ft. deep. The limestone was worked intermittently by Jairam Valjee, mainly for the production of quicklime.

Katang.

North-north-west of the Sonakhan railway station, and two furlongs to the north of the Katang village, is an abandoned quarry in limestone, on the southern flank of a hillock. The

dimensions of the quarry are roughly 300 ft. by 100 ft. It has reached, in places, a depth of 25-30 ft.

Kukarbhuka.

There is a small abandoned quarry in limestone immediately to the west of the western hamlet of Kukarbhuka. A small knoll of limestone, not more than 40 ft. high, is found here, on the southern side of which some quarrying has been done. The limestone is dark, medium- to fine-grained, flaggy, and generally impure. The quarry is 220 ft. long along the strike, and 50 ft. across. It has reached down to only a few feet below the ground level.

Some 30 ft. to the east of the quarry is a trench 70 ft. long (north-south) and 15 ft. broad. This was evidently excavated for prospecting purposes. The quarry seems to have been worked only experimentally and then closed.

Jharbera.

In the Dublabera syncline, there are too small quarries in dolomite. They are quite shallow and have not been developed to any appreciable extent.

Birmitrapur.

The limestone and dolomite bands here have comparatively greater width than elsewhere, except in the folds of the eastern end of the anticlinorium. Dolomite occurs to the south of the limestone and occupies the plain, while the limestone forms hills, which are locally called the Patpahar, Gurpahar, and Manipahar, respectively, from east to west. The dolomite exposures are to a large extent covered by soil. The quarries in dolomite, situated to the south of Gurpahar, are now filled with water. As mentioned in the geological section of this memoir, the limestone exposure is 750-800 ft. wide in the pass between the Patpahar and Gurpahar, and 1,000-1,050 feet wide in the pass between the latter and Manipahar,

The quarrying, which is now entirely confined to the limestone hills, is being gradually extended westwards. The quarries take the form of long trenches along the strike of the rock, the impure bands being left as ridges. Most of the work is now done near the tops of the hills. There are tramlines laid at different levels conveniently situated with respect to the workable bands. The quarried stone is loaded in steel tubs which are generally pushed by hand and emptied at the storage bins. From these the stone is sent down the hillside on inclined chutes, constructed of steel sheets, to storage bins at ground level, whence it is loaded into railway waggons for despatch.

Plate 9, fig. 1 shows the general view of the Gurpahar (as in January, 1928) with two chutes in the centre. Plate 11 shows the arrangement of tramlines at different levels in a part of the Manipahar near the large battery of lime kilns, and a chute down which the stone is sent to a storage bin below.

The stone is first shattered by light blasting and then broken up by hand to lumps measuring 3 to 6 inches across. After being loaded in the railway waggons, which usually take about 20 tons, the material in each waggon is sampled by taking a vertical column of lumps about 6 to 8 inches in diameter. The samples are analysed in the laboratory situated at the south-eastern end of the Gurpahar, the insolubles and magnesia being usually determined. If the stone in any particular waggon does not come up to the required quality, then it is generally used in the kilns for making lime. This does not happen frequently, since the quality of the stone from the different bands is known by previous analyses and experience. Some of the bands are regularly worked for lime-burning as in the Manipahar. Here, on the northern foot of the hill close to the site of the Bannunda village (22° 25′ : 84° 43′), is a battery of sixteen kilns, a view of which is shown in Plate 9, fig. 2. I am indebted to Mr. R. F. Alexander of the Bisra Stone Lime Co., Ltd., for the following description :—

' Calcining of the limestone is carried out in vertical kilns of the continuous burning type, which are in a battery of sixteen. Each kiln has an outturn capacity of from 15 to 18 tons of lime daily. Specially selected limestone is quarried at Duar Sini, about half a mile from the kilns, and is trammed from there to a 500-ton bunker on the hillside opposite the kilns. It is then discharged into runway tubs and fed direct from them into the kilns with the necessary proportion of coal. The bottom and doors of the kilns are designed so as to be self-discharging. The

lime as drawn from these is conveyed in ropeway tubs and discharged over screens, to eliminate dust and ash, into a lower ropeway which carries it to the packing floors to be loaded into broad gauge railway waggons.'

There are also a few other, single, kilns, some being built in solid rock on the hillside near the foot of the hill. One such kiln is seen in Plate 9, fig. 1.

By far the greater part of the limestone railed (about 90 per cent. or more) from Birmitrapur is consumed in the iron smelting furnaces of the Tata Iron and Steel Co., the Indian Iron and Steel Co., and the Bengal Iron Co. A small quantity is also shipped to other firms and used for various purposes. Much limestone is also quarried for burning in the kilns. In the tables of production given on a later page, the tonnage used for manufacturing lime is shown separately from that exported as limestone, where available. The lime is distributed to various populous centres within easy reach, the chief markets being Calcutta, Jamshedpur and the towns in the coalfields where it is well known under the name of 'Bisra lime'.

Quality.

Almost any composition ranging from a pure limestone or dolomite on the one hand, to a shale, phyllite or quartzite on the other, can be matched in the field from different portions of the exposures. Here, however, we are concerned with the average quality of the material ordinarily exported from, or used at, the different quarries.

The greater part of the limestone and dolomite won in the Gangpur State has been used in iron-smelting furnaces. In general, iron and steel companies require limestone in which the following impurities are allowed :- a maximum of six per cent. total silica and alumina, of which up to five per cent. may be silica, and a maximum of 4·5 per cent. magnesia. The Tata Iron and Steel Co. are said to stipulate that the magnesia content should not exceed 3·5 per cent., since a larger content affects the coke consumption and the composition and viscosity of the slag. Ferruginous material, provided there is no sulphur in it, is not objected to.

In the case of lime manufacture, a somewhat larger latitude in composition can be allowed, but the iron content must be very low, so that the lime burns white.

The following table shows the composition of limestone won and *utilised* :—

TABLE 17. —*Analyses of Birmitrapur limestones.*

—	Open hearth furnace.			Blast furnace and lime manufacture.				
	1	2	3	4	5	6	7	8
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent	Per cent	Per cent
Silica . . .	2·00	2·20	2·26	3·34	2·71	3·42	3·10	4·72
Alumina . . .	0·50	0·20	0·40	0·43	1·22	0·59	0·55	0·80
Ferric oxide . .	..	.	.	0·52	0·81	0·56	0·60	..
Lime . . .	..	..	.	49·01	50·89	49·15	49·41	48·50
Magnesia . .	2·85	3·00	3·57	3·81	2·63	3·55	3·56	3·38
Loss on ignition . .	..	.	..	41·75	..	41·79	42·13	..

The above analyses were kindly supplied by Mr. R. F. Alexander of the Bisra Stone Lime Co., Ltd. The Birmitrapur exposures have been sampled along several lines at intervals, in a north-south direction, *i.e.*, across the strike of the beds. One such sampling line, measuring about 1,020 ft. across the Gurpahar, gave, according to information kindly supplied by the late Mr. Gordon Duff, formerly Managing Director of the Bisra Stone Lime Co., an aggregate width of 150 feet of limestone with less than five per cent. silica, 350 feet containing between five and eight per cent. silica, and the rest containing between 8 and 25 per cent. of the same constituent. The alumina and ferric oxide content are generally low, averaging between 0·7 and 1·5 per cent. The magnesia content, in the portions which show eight per cent. or less of silica, ranges between two and six per cent., but occasionally going up to 16 per cent. The bands with a particular composition are generally persistent for several hundred feet along the strike, but may broaden, thin out, or be gradually replaced by material of different composition.

In the following table are given some analyses of limestone from the Amghat quarries :—

TABLE 18.—*Analyses of Limestone from Amghat.*

—	1	2	3	4	5	6	7	8	9
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	per cent.	Per cent.	Per cent.
Insolubles (mainly silica).	2·91	2·07	6·22	5·61	6·30	7·54	11·58	18·59	7·72
Alumina . .	2·26	1·33	1·12	1·11	1·06	1·16	2·00	2·23	1·56
Lime . .	47·00	51·05	50·92	48·38	47·97	46·04	45·24	37·53	45·82
Magnesia .	5·94	2·12	1·09	3·05	3·28	3·05	3·27	6·00	4·42
Loss on ignition	41·90	42·44	43·20	41·15	40·22	40·24	38·12	35·40	39·91

The above, selected from about 30 analyses kindly supplied by Messrs. Tata Iron and Steel Co., Ltd., are specially designed to show the variations in composition of material from different bands of the limestone bed at Amghat. The last, No. 9, represents the average of all the samples from a sample trench across the strike of the limestone. The average quality shipped from the quarries to their works at Jamshedpur was confined to the bands which analysed less than 5 per cent. insolubles and less than 4 per cent. magnesia.

Some analyses of dolomite representing material from Birmitrapur are given below.

TABLE 19.—*Analyses of Dolomite (Birmitrapur).*

—	White.	Grey.	Ordinary. 1	Ordinary. 2
	Per cent.	Per cent.	Per cent.	Per cent.
Silica	1·13	2·61	3·00	3·11
Alumina	0·12	0·18	0·73	1·62 (Alumina and Ferric oxide)
Ferric oxide	0·50	0·18	0·62	
Lime	29·06	30·10	29·26	30·01
Magnesia	20·38	20·61	20·11	19·22
Loss on ignition	46·60	46·02	44·67	..

In the following table are given seven analyses of dolomite from Amghat selected from a large number, courteously supplied by the Tata Iron and Steel Co., Ltd.

TABLE 20.—*Analyses of Dolomite (Amghat).*

—	1	2	3	4	5	6	7
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Insolubles (mainly silica).	0·68	1·30	3·60	4·92	7·38	9·38	8·06
Alumina	0·50	1·32	1·19	1·88	2·66	1·84	1·15
Lime	30·36	30·11	29·45	30·25	28·75	27·25	29·00
Magnesia	21·54	21·12	20·79	18·43	17·32	19·44	20·37
Loss on ignition	46·52	46·08	44·10	43·60	43·00	41·58	44·04

In this table also the last column gives the average of a large number of analyses representing a series of samples taken across the strike of the dolomite beds in a sampling trench. A comparison of this, with the average for the limestone samples given already, will bring out the comparative purity of the dolomite beds. It is only occasionally that portions of the dolomite run to over 4 per cent. insolubles. In fact, it is known that from one of the quarries in Amghat the company had uniformly despatched dolomite averaging less than 2 per cent. insolubles.

In Table 21 are grouped together a few analyses of dolomite from Messrs. B. P. Byramjee & Co.'s Usra quarry and those of two fairly representative specimens collected from the exposure in the stream near Lifripara.

TABLE 21.—*Analyses of Dolomite (Usra and Lifripara).*

<table>
<tr><th>—</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td></td><td>Per cent.</td><td>Per cent.</td><td>Per cent.</td><td>Per cent.</td><td>Per cent.</td></tr>
<tr><td>SiO_2 . . . . . .</td><td>0·20</td><td>3·04</td><td>1·20</td><td>1·33</td><td>1·33</td></tr>
<tr><td>Al_2O_3 . . . . . .</td><td rowspan="2">0·02</td><td rowspan="2">1·80</td><td>0·46</td><td>0·64</td><td>0·48</td></tr>
<tr><td>Fe_2O_3 . . . . . .</td><td>0·81</td><td>0·67</td><td>0·71</td></tr>
<tr><td>CaO . . . . . .</td><td>30·54</td><td>30·73</td><td>30·83</td><td>30·34</td><td>30·41</td></tr>
<tr><td>MgO . . . . . .</td><td>20·78</td><td>20·67</td><td>21·87</td><td>21·47</td><td>21·43</td></tr>
<tr><td>Loss on ignition . . .</td><td>48·02</td><td>43·48</td><td>..</td><td>..</td><td>..</td></tr>
<tr><td>Sp. Gr. . . . . .</td><td>2·88</td><td>2·85</td><td>..</td><td>..</td><td>..</td></tr>
</table>

1. Specimen 43/170 from the stream bed near Lifripara.
2. Specimen 43/175 from a different part of the same exposure. Contains a little tremolite, quartz and micaceous matter.
3, 4, 5. Average analyses of shipments from the Usra quarry for the years 1929, 1930 and 1931, respectively. (By courtesy of the Tata Iron & Steel Co.).

The occurrence of calcareous flags grading into phyllitic shales near Dhelsara has been already mentioned (*see* p. 85-86). These calcareous rocks extend along the strike for a distance of nearly six miles. Sections of this are seen in the stream south of Dhelsara and along the Deo river between Dhelsara and Pharsa, where these rocks are not less than 450 ft. thick. A specimen (45/753), collected from the lower part of the bed, gave the following analysis :—

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	H_2O	Ign.	Total.
12·18	3·64	2·20	43·10	1·88	0·52	36·76	100·28

Sp. Gr.=2·748.

This corresponds to 76·93 per cent. calcium carbonate and 3·93 per cent. magnesium carbonate, the rest being quartz and shaly material.

The analysis shows that the material is not of a high quality, But the quantity of available material of this and of more shaly composition is very large. I am of the opinion that certain parts of the deposit will prove to be a suitable hydraulic limestone or natural cement-stone. Investigations of this occurrence as well of the shaly bands in the main limestones of the anticlinorium seem worth while for the purpose mentioned here.

Quantity available.

Limestone, Birmitrapur.

I made a rough estimate of the quantity of limestone available in the Birmitrapur area, using such data as were available. Assuming a total length of four miles (say, 21,000 feet) and an average thickness of 850 feet the total quantity of limestone per 100 feet depth (on the basis of 13 cubic feet per ton) will be: -

$$\frac{21{,}000\times850\times100}{13}=137{,}300{,}000 \text{ tons approximately.}$$

Of this amount, roughly 10 per cent. can be classed as first grade (fit for metallurgical purposes) and 25 per cent. as second grade and useful for lime making. We may take further that the average height of the hills in this area above the general ground level is not less than 100 feet and that limestone can be worked to a depth of 100 feet below the ground level without much difficulty. On this basis the above quantity will be doubled, giving 27,460,000 tons of first grade and 68,700,000 tons of second grade stone. In the absence of detailed information, the above figures are considered to give a fair and conservative estimate of the quantity available.

Dolomite, Birmitrapur.

With regard to dolomite, it is known that the strata are of greater purity than the limestone so that about a third of the total volume of the rock may be utilisable. The area occupied by the dolomite is certainly larger than that occupied by the limestone, but as the outcrops are all on ground level, a total workable depth, by open-cast methods, of 150 feet, may be taken. On the basis of an area of 21,000×1,000 sq. ft., a workable depth of 150 ft., and a volume of 12·5 c. ft. to the ton, the total quantity of dolomite available

will be 252 million tons. Of this quantity, a third (84 million tons) may be expected to be of high grade.

A conservative estimate was also made of the dolomite of good quality available in the Lifripara exposure. Assuming a length of 1,500 ft., an aggregate thickness of 50 ft., a workable depth of 100 ft., and calculating at 12·5 c. ft. of rock per ton, we obtain a quantity of 600,000 tons. This does not take into account the extension of the beds eastwards near Surgura. The Lifripara exposure is however the least accessible of all the occurrences in Gangpur, being about 25 miles from the railway. Nevertheless, the presence of a good deposit of dolomite there is bound to be of some use at a future date (*see* p. 150).

Dolomite, Lifripara.

I have not attempted to work out any figures for the other outcrops, as the necessary data are not available; and in any case, without the aid of figures derived from detailed prospecting, the estimates could only be very approximate. Nevertheless, it will be seen from the indications given by the above estimates, that the quantity of good limestone and dolomite available in Gangpur State must be of the order of several hundred millions of tons.

Production.

From the foregoing sketch of the history of the limestone and dolomite mining in the State, it will be gathered that the exploitation started with the most easily accessible deposits. The occurrence of a line of hills at Birmitrapur containing very good limestone induced the Bisra Stone Lime Co. to transfer their activities from the several comparatively small exposures near Bisra, to Birmitrapur, where their expectations have been amply fulfilled.

In the following table are given the figures of production of the different groups of quarries. No figures are available for the years preceding 1912, though it is known that, practically since 1900, limestone and lime have been exported from the Gangpur State. The Bisra Stone Lime Co., Ltd. and their predecessors have been the chief producers during all these years. They worked first near Bisra, then at Katang and lastly at Birmitrapur. The Tata Iron and Steel Co. worked mainly between 1919 to 1928, at Panposh and Amghat. In 1933 again they have started quarrying dolomite at Panposh near the river bank. Messrs. B. P. Byramjee & Co. had been working the dolomite quarry at Usra from 1919 to 1930. There has also been sporadic working and a small production by the Gangpur Stone Lime Co. and by Jairam Valjee.

TABLE 22.—*Production and value of Limestone in Gangpur State.*

—		1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.	1922.
B. S. L. Co.	Tons.	28,516	25,700	24,250	10,920	88,710	*1,009	*62,571	*11,880	(b)67,319*	(b)54,296	* 76,108
	Rs.	28,516	25,700	24,250	10,920	204,985	2,018	2,478	26,730	159,883	40,722	114,162
Others	Tons.	..	..	..	..	..	..	2,000	..	..	..	..
	Rs.	..	..	..	..	..	..	500	..	..	..	..
B. S. L. Co.(Katang)	Tons.	..	..	..	..	..	..	..	64,222	28,371	68,701	..
	Rs.	..	..	..	..	..	..	..	144,500	67,381	51,525	..
T. I. S. Co.(Amghat)	Tons.	..	..	..	..	..	..	..	20,439	3,060	92,239	..
	Rs.	..	..	..	..	..	..	..	40,878	6,120	184,478	..

—		1923.	1924.	1925.	1926.	1927.	1928.	1929.	1930.	1931.	1932.	1933.
T. I. S. Co. (Panposh)	Tons.	..	..	..	9,404	..	..	..	..	..	..	..
	Rs.	..	..	..	5,460	..	..	..	..	..	..	..
G. S. L. Co.	Tons.	..	..	1,000	40	..	..	..	..	(c) 334	1,856	..
	Rs.	..	..	2,000	440	..	..	..	..	1,43[illegible]	..	..
B. S. L. Co. (Birmitrapur)	Tons.	74,180	119,000	275,068	237,012	455,000	410,052	526,353	511,040	363,448	[illegible]	[illegible]
	Rs.	111,270	178,500	412,602	400,513	[illegible]	820,103	1,052,766	1,149,[illegible]	[illegible]	[illegible]	[illegible]
B. S. L. Co. (Birmitrapur for lime)	Tons.	..	..	..	53,515	35,678	71,504	69,245	73,008	[illegible]	[illegible]	[illegible]
	Rs.	..	..	..	67,289	133,113	169,055	138,466	164,273	[illegible]	[illegible]	140,224
T. I. S. Co. (Amghat)	Tons.	10,398	44,509	72,865	[illegible]	103,475	27,372	..	..	..	..	..
	Rs.	42,118	178,088	216,555	[illegible]	333,754	39,401	..	..	..	..	..

* Birmitrapur. (b) Includes some d[illegible]. (c) Includes 216 tons for lime manufacture.

TABLE 23.—*Production and value of Dolomite in Gangpur State.*

—		1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921	1922
T. I. S. Co. (Panposh).	Tons. Rs.	40.465 80,930	90.403 180,816	97,260 194,532	97,343 194,687	84,632 169,264	108,710 217,420	124,031 248,063	121,692 243,334	83,237 166,475	90,623 181,247	88,500 177,000
B. S. L. Co. (Bir-mitrapur)	Tons. Rs.	.. ..	.. ..	.. ..	.. ..	.. ..	46.060 92,120	5.126 2.999	.. ..	(a) ..	(a) ..	.. ..
T. I. S. Co. (Amghat).	Tons. Rs.	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	51,585 103.170	70,231 140,462	92,239 184,478	121,401 242,802
B. P. B. Co. (Usra)	Tons. Rs.	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	781 781	.. ..	.. ..	8,476 12,714

—		1923.	1924.	1925.	1926.	1927.	1928.	1929.	1930.	1931.	1932.	1933.
T. I. S. Co. (Panposh).	Tons. Rs.	98,359 196,718	92,120 184,240	59,984 179,952	7,936 12,478	9,235 18.518	.. ..	.. ..	.. ..	.. ..	.. ..	11,926 .
B. S. L. Co. (Bir-mitrapur)	Tons. Rs.	9,963 14,948	21,000 31,500	65,072 97,608	33,789 67,578	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	327 735
T. I. S. Co. (Amghat).	Tons. Rs.	84,741 348,406	166,193 664,771	160,818 482,454	56,378 190,253	.. ..	.. ..	(b) 162 218	.. ..	.. ..	.. ..	.. ..
B. P. B. Co. (Usra)	Tons. Rs.	10,387 15,580	21,240 53,100	30,707 76,768	37,276 93,190	50,444 126,110	17,990 44,975	24,206 72,618	25,445 76,335	(c) 12,170 ..	.. ..	(c) 1,391 4,027

(a) Included under limestone. (b) From Tongritola near Amghat. (c) No raising, despatch only.

CHAPTER XVI.—OTHER MINERAL PRODUCTS.

Coal.

An account of the occurrence of coal-bearing rocks has already been given in the chapter describing the Gondwanas. In that section a short summary of King's exploratory work on the coal seams and the results of analyses of the borehole samples then obtained have also been included. It will be seen from there that the coal was of poor quality. Though some samples which were taken from surface exposures gave somewhat better results, King concluded that further work in the area was not likely to prove profitable.

The results of analyses of eight specimens from the coal outcrops near Rattansara are given by King, and these show the following range in composition:—

Moisture between	3·72	and	12·26	per cent.
Volatile matter between	24·98	,,	32·82	,,
Fixed carbon between	29·20	,,	50·60	,,
Ash between	6·52	,,	42·10	,,
Average ash content	21·51			,,

I collected a few specimens from the coal outcrop in the Baisundar just above its confluence with the Jhajia *nala*, north of Gopalpur. The specimen which appeared to be the best was analysed in the Geological Survey Laboratory with the result given below. Some vitrain from the vitrain-ochre band in the same section was also analysed:—

TABLE 24.—*Analyses of Coal and Vitrain.*

—	Coal.	Vitrain.
	Per cent.	Per cent.
Moisture	4·24	6·80
Volatile matter	32·98	32·62
Fixed carbon	43·74	59·04
Ash	19·04	0·94
Caking	Does not cake	Does not cake
Colour of ash	White	Drab
Sp. Gr.	1·427	1·346

The above analysis of coal also supports King's conclusions. It is known that some years ago the Rampur Coal Co. conducted some prospecting operations near Dulanga and Siarmal (south of Tiklipara). The results are not available, but from the fact that nothing further has been done, it may be inferred that the results were far from encouraging. Whether coal-washing and carbonisation processes, which are being tried in the West, can utilise the coals available here is for the future to decide.

Gold.

The metamorphic rocks of Gangpur and adjoining territories and the quartz veins associated with them are reported to be gold-bearing. Gold-washing was carried on in the Mahanadi, the Ib and their tributary streams during the last century. Colonel Haughton[1] has recorded the occurrence of gold in the sediments contributed to the Koel, Karo, Sankh and Brahmani rivers.

According to Ball,[2] gold-washing was regularly done at Anandpur (22° 28′ : 85° 10′) and at Dipa two miles to the south-south-east of the former. The tradition seems to have persisted down to very recent times. On Surgeon Breton's authority, he states that gold mines existed in Gangpur State and that large pieces of native gold were found in one of the mines. The same author has remarked[3] on the gold-bearing nature of the rocks in Gangpur and Sambalpur. The Ichha *nala* in Gangpur is said to contain the precious metal.

J. M. Maclaren[4] has studied the gold occurrences of Chota-Nagpur and has shown the following places in the map accompanying his paper as supporting gold-washing operations:—

—Junction of the Koel and Karo rivers north of Anandpur.
—The Koel river near Anandpur and Dipa.
—The Koel near Jaraikela and the Brahmani near Raghunathpali.
—Giringkela and Sargipali on the Ichha *nala*.
—Kusumura and Sarbahal on the Ib.

[1] *Jour. As. Soc. Beng.*, XXIII, p. 110, (1854).
[2] Manual of the Geology of India, Part III, pp. 195, 196, (1881).
[3] On the diamonds, gold and lead-ores of the Sambalpur district. *Rec. Geol. Surv. Ind.*, X, pp. 186-192, (1877).
[4] J. M. Maclaren, The auriferous occurrences of Chota-Nagpur. *Op. cit.*, XXXI, pp. 59-91, (1904).

In the same paper[1] are given the values obtained by F. H. Smith from washings carried out in several places.

Locality.	Gold in grains per cubic yard.
Sukha *nala* at Ankua	2·1
Sukha *nala* at Ankua	2·3
Sukha *nala* at Ankua	2·8
Sukha *nala* at Ankua	0·6
Gundria (? Kamarbora) 2½ miles S.E. of Manoharpur	2·8
Koel river near Manoharpur	0·6

Maclaren has expressed the opinion that the gold is genetically connected with the epidiorites of the area and not with the granite.

Sir T. H. Holland considered the gold occurrences in the hills between Ankua and Monoharpur as doubtful propositions, though these were—

> 'mentioned on account of the rich, coarse alluvial gold found in the immediate vicinity, of the rich specimen of auriferous quartz picked up in the Ankua stream and of the existence of large, well defined quartz reefs in the neighbourhood.'[2]

F. H. Hatch carried out an investigation of the rocks at Pahardia[3] (22° 30′ : 85° 12′), where some shafts had been sunk by a mining concern. The rocks at that locality were quartzites veined with secondary quartz and associated with calcite-bearing chlorite-schist. Of the five shafts sunk, veins occurring in No. 3 were sampled at depths of 50 feet and 70 feet, yielding 4·5, 3·25 and 1·3 dwt. per ton. Shaft No. 4 revealed rocks with 2 dwt. and Verner's shaft gave 7·8 dwt. and 5·2 dwt. per ton. The veins in these were found to be mineralised quartzite bearing pyrite and gold. Dr. Hatch thought that the occurrence was sufficiently encouraging for the continuance of the work, but the prospecting operations seem to have been stopped soon after.

[1] *Ibid.*, pp. 90-91.

[2] General Report of the Geological Survey of India for the year 1902-1903, p. 12, (1903).

[3] Report on the auriferous quartzites of Pahardiah, Chota-Nagpur. *Mem. Geol. Surv. Ind.*, XXXIII, Pt. 2, pp. 68-71, (1902).

Among the collections of the Geological Survey of India are a few samples of native gold and gold concentrates obtained from the Sankh and Brahmani rivers in the year 1884 (H. 665 to H. 670 in the mineral collection). There is also a record of a small nugget of gold, weighing 1·4616 gms. (P. R. No. 1531), obtained by a prospector from the sands of the Brahmani river close to the railway bridge near the Panposh railway station.

Since the commencement of the present century, which coincided with the construction of the Bengal Nagpur Railway through this region, gold-washing seems to have ceased as a remunerative occupation for the people who formerly undertook it. Only in one place, in the small stream joining the Koel river just west of San Bamua, did I hear of the local people having panned the sands for gold in very recent years. A day's work is said to bring concentrates of the value of four to six annas. I have also been able to confirm that gold was formerly obtained at Anandpur, Raghunathpali, Sargipali, Kusumura and other places.

Lead-ore.

The occurrence of lead-ore in Gangpur State was known to Dr. Ball, who states[1]:

> 'To the north of Sambalpur, near Talpuchia (Talpatia—21° 57′: 84° 1′) on the Ebe (Ib), some rolled pebbles, consisting of a mixture of oxide and carbonate of lead, have been found. Whence they were originally derived is uncertain, but I think it possible that the matrix may exist in a small hill to the north of Talpuchia which consists of fault rock and gossan.'

On assay, this material was found to contain 87·28 per cent. of lead.[2]

In the course of the survey I examined the hillock of fault-breccia near Talpatia referred to above, but no veins of galena were found. But veins of galena occur near Sargipali only ten miles to the north-west. It is possible that the mineral, accompanied by its alteration product cerussite, has been transported by the Ichha *nala*, which flows past Sargipali, into the Ib.

[1] V. Ball, On the diamonds, gold and lead-ores of the Sambalpur district. *Rec, Geol. Surv. Ind.*, X, p. 192, (1877).

[2] Manual of the Geology of India, Pt. III, p. 295, (1881).

Sargipali.

A mile to the south-east of Sargipali (22° 3′ 30″ : 83° 55′) and just north of the hill 1251 is a trench, which is nearly a mile long, 60 feet wide and up to 20 feet deep. It has an approximately east and west trend corresponding roughly to the strike of the schists. How long ago the trench was excavated is not known, since no one living in those areas has any knowledge of its early history. Neither is there any tradition among the local people nor information in the State records about its history. It is probable therefore that it is at least two centuries old.

Old trench.

The country rock is mica-schist dipping towards S. 15° W. at an angle of 45° to 50°. On examining the dumps on both sides of the deepest part of the trench, I found pieces of mica-schist with films and thin crusts of malachite. Traces of galena were present in several specimens, and in one case a few minute hexagonal crystals of pyromorphite. About 10 years ago a prospector had sunk a few pits in the trench in search of metalliferous veins, but none of the pits had revealed any.

About two furlongs north of this trench, and a short distance from the bank of the Ichha *nala*, is a long narrow strip of country measuring about 400 yards by 15 yards which has been recently brought under rice cultivation. The villagers found that the *paddy* here grows well at first, but after some time, just at or before the appearance of the 'ears,' is rapidly parched.

In excavating the soil and lowering the level of the field, the villagers found small heavy white lumps of *kankary* material, which they showed me when I was mapping the neighbourhood. These lumps, on testing, were found to be made up of lead carbonate. At my suggestion, the State authorities had three pits put down along this strip. Though none of these reached solid rock at depths of 10 to 13 feet, more lumps of lead carbonate were found. One of these, when broken, showed a core of galena. All these lumps are creamy to buff in colour, and irregular in shape. Freshly broken surfaces show a pink colour and coarsely crystalline texture (N. 489), and are also somewhat porous. One of them gave a specific gravity (at 25°C.) of 5·9, that of pure cerussite being 6·5. The lumps when tested in the laboratory were seen to consist of lead

Parallel zone with soil containing lumps of lead carbonate.

carbonate with a trace of lead sulphate and a little clayey or aluminous matter. No silver could be detected in them.

From the distribution of lead carbonate in this zone, it is thought that it represents the soil derived from the weathered rock with veins of galena, the disintegration and alteration of which gave rise to the lumps. The effect on the rice plant is to be attributed to the sulphur content in the sub-soil, water from which will be drawn on by the plants a few months after the cessation of the monsoon, by which time the plants grow up.

Prospecting pits. Towards the end of March 1932, Mr. H. D. Christian, Superintendent of Gangpur State, had pits put down in the long trench at three localities selected by me. Pit No. 1 was located near the western end of the trench, about one furlong east of a small *nala*. The pit was 12 ft. 6 in. long (north and south), 7 ft. wide (east and west) and went down to 22 ft. depth from the bottom of the trench. Solid mica-schist was met with at 19 ft. depth. The northern portion showed dark botryoidal limonitic matter and thin stringers of galena (specimen A), while films of malachite (specimen B) were met with in the southern portion. A fair amount of water collected at the bottom, but this could easily be baled out. Pit No. 2 was 400 ft. from No. 1 in an E. 20° S. direction, the dimensions being 15 ft. (north and south) by 6 ft. (east and west) and 21 ft. in depth. Near the southern edge of the bottom, a vein of galena 6 in. thick was met with in mica-schist. In the surrounding schist there were thin stringers of galena and a little chalcopyrite (N. 658 specimen C). The middle of the pit was occupied by a thin sill of tourmaline-pegmatite, which was evidently responsible for imparting a fair degree of hardness to the schists in its vicinity.

Pit No. 3 was excavated at a spot 750 ft. distant from No. 2 in an E. 15° S. direction. It was 17 ft. long (north and south), 10 ft. wide (east and west), and 20 ft. deep. The northern portion of the bottom was in solid mica-schist while the southern portion was still in debris. A specimen containing disseminated galena (specimen D) was collected from the schists at the bottom of this pit. Later in the same summer, some further deepening of the pits was done. No. 1 was deepened to 27 ft. without, however, showing any encouraging signs of ore. No. 2 went down to 23 ft., the galena vein persisting and dipping steeply southward. The schists at the bottom were quite hard, so that further work would have necessitated blasting.

The promising representative hand specimens collected from these were assayed in the Geological Survey laboratory by Mr. Mahadeo Ram, with the following results:

TABLE 25.—*Assays of lead-ore from the old trench near Sargipali.*

—	A	B	C (N 658)	D
Copper (per cent.)	0·44	0·11	0·15	0·20
Lead (per cent.)	3·05	0·00	1·30	1·13
Silver (dwt. per ton)	9·20	*Nil*	22·20	11·80

The result of the assays shows that the trench and its neighbourhood are well worth further investigation. Mr. Christian informs me that, in the present state of the base-metal market, it has not been possible to interest mining concerns in the proposition. Should further exploration confirm the promise held out by the specimens examined, the ores in this area may be a valuable addition to India's poor resources in lead and silver. The locality is about 17 miles from the railway, and within easy reach of the coalfields.

Kumbakera[1].

Galena was reported to occur at Kumbakera (22° 29′ : 84° 44′ 30″) in the Simdega sub-division of the Ranchi district. On investigation, however, the occurrence proved disappointing.

A few years ago, the Zamindar of Biru discovered a small vein or pocket of galena on the northern slopes of the hill on which Kumbakera is situated, about half a mile to the north-west of that village. He had had two excavations made here, close to each other, one measuring 10 ft.×10 ft.×12 ft., and the other 40 ft.×10 ft. ×10 ft., the length being along the direction of strike of the rocks. The country rock is mica-schist dipping fairly steeply towards the S. S. E. A thin sill of weathered epidiorite is seen on the S. S. E. wall of the larger excavation. Only traces of galena were found in the debris in the trench, associated with somewhat spongy vein-

[1] *Rec. Geol. Surv. Ind.*, LXV, p. 52, (1931).

quartz, but none was found *in situ*. A specimen (N. 363) of the ore, which was obtained from the headman of the village, is good crystalline galena. Another, which was lent to me for examination, showed galena in association with vein-quartz, the contact between the two minerals showing a thin film of chlorite in places. Information gathered locally went to show that a small galena vein outcropped at the place now marked by the smaller of the two pits. This, when opened up, was found to be nothing more than a lens or pocket, yielding only about 300 lbs. of galena. The larger pit was opened up by the Zamindar in the hope of finding more ore, but with negative result. As there was a complete absence of further indications in the neighbourhood, when I visited the area in 1930 and 1933, it may be concluded that the original occurrence was of the nature of a sporadic pocket and that the prospects of finding more ore are poor.

Pyrites.

About two furlongs to the north-west of Barloli (22° 29′ : 84° 45′) a zone of pyrite impregnated mica schist was found on the bank of a small stream. In April, 1930, when I visited this area, this occurrence had been opened up by the Zamindar of Biru by a shallow trench measuring 15 ft.×4 ft.×4 ft. The mica-schist is impregnated heavily with fine-grained pyrites for a width of four to five feet, and also contains a few veins of the same mineral rarely exceeding one inch in width. The pyrite extended along the strike of the schists. At the surface, the schist containing the pyrite had decomposed to a grey clay with efflorescence of white alum. A specimen from this occurrence, when tested for gold, showed only a trace of that metal. Later on I learnt that the trench was continued along the strike of the rocks and was also deepened. But after a distance of a few feet in either direction, the pyrites content diminished rapidly and disappeared. Further work on this was abandoned as the deposit was too small to be of any economic value.

Diamonds.

Sambalpur is known to have produced diamonds, the best known locality being the Heera Kund in the Mahanadi, a few miles above Sambalpur town. Dr. Ball, who had gone into the question

of the occurrence, found that the Ib was not a contributor of this mineral, but added[1]:—

'It should be stated, however, that one of the tributaries of the Ebo, the Icha, far away in Gangpur, is said to produce diamonds, but the statement needs confirmation......Near its sources, far away in Chota Nagpur, I have heard of the Ebo spoken of as *Hira nad*.'

Two pebbles, suspected to be diamonds, are said to have been found by fishermen and gold-washers in the Ib river near Gailo (22° 16′ : 84° 5′) about 25 or 30 years ago, and presented by them to the late Raja of the State. The stones are said to be in the treasury of the State, but it is not known if they are genuine diamonds.

REFRACTORIES.

Kyanite.

Kyanite occurs in association with vein-quartz in many places in the area under consideration, but all the occurrences are comparatively small lenses and of no economic value. The following may be mentioned. South of the village of Sialjor (22° 12′ : 84° 27′) there is a small lenticular area close to the Gangpur-Bamra boundary. A somewhat larger occurrence was noted at a locality about half a mile south-west of Kodumunda (22° 23′ : 84° 32′), adjoining an exposure of tremolite-schist. Several small lenses have been observed near Ghoriajor, Kumbakera and Alapaka.

Sillimanite.

The occurrences of this mineral are also very restricted and only of academic interest, as in the case of kyanite. In the hills composed of quartzites and quartz-schists south of Kahobua (22° 4′ : 84° 31′), bundles of fibrous sillimanite occur, the mineral forming about three to five per cent. of the rock. As the mineral is mostly microscopic in size, I have not been able to determine the extent of the deposit.

Sillimanite occurs as an accessory mineral in some of the garnetiferous gneisses, but these are of no economic value.

[1] *Rec. Geol. Surv. Ind.*, X, p. 189, (1877). '*Hira*' is the Hindi word for diamond.

The Barakar shales occurring in the Himgir *zamindari* are locally of good quality and can be used as fire-clay. One such exposure occurs near Kirpsera (21° 59' : 83° 47') covering an area of at least 700 yards by 200 yards. A specimen collected very close to the above village possesses plasticity and is resistant to heat at 1400°C. It is light grey in colour, but on burning becomes nearly white, contracting by about 20 per cent in volume. I have, however, no data about the thickness or variation in quality from place to place.

Other places in the strip of Talchirs and Barakars bordering on the boundary of the metamorphics are worth investigation as to the quality of the clays available.

Three specimens of clay, collected at Birmitrapur from the strata between the limestone and epidiorite, in the railway cutting between the Manipahar and Gurpahar, are also fire-clays. The shrinkage in volume varies between 21 per cent. and 39 per cent. The original colours of the specimens which were tested were white, white with pink streaks, and bluish grey. On burning, these became respectively, white, wood-brown and lavender grey. These are also worth further investigation.

Kaolin and white clay.

Pockets of kaolin are frequently associated with exposures of pegmatitic veins as products of decomposition of the felspar. Even the best occurrence, *viz.*, that near Manjapara, is of small dimensions and can yield only a small tonnage. Chandoke[1] has described the Manjapara occurrence, where the felspar veins in pegmatite have been completely kaolinised. An average sample of the kaolin gave, on analysis:

	Per cent.
SiO_2	45·67
Al_2O_3	39·17
Fe_2O_3	0·63
CaO	0·62
MgO	0·31
H_2O	12·24
Na_2O, K_2O	0·36
	99·00

[1] D. P. Chandoke, Note on the Kaolin deposits near Manjhapara, Gangpur State. *Trans. Min. Geol. Inst. Ind.*, XXVII, pp. 145-152, (1933).

The clay possesses poor plasticity and crumbles on burning at 1400°C., without showing any signs of fusion. It can be used as a 'filler' and also for ceramic bodies if mixed with felspar.

From what can be seen on the surface, the deposit is irregular and of small size, so that it may be expected to contain only a few hundred tons of good kaolin. At present the villagers scoop out the kaolin at convenient spots and use it for the whitewashing of houses.

The Barakar sandstones around Amatpani, and especially at the head of the valley one mile to the north-west of the village near the Raigarh border, contain good white kaolinic clay as the matrix. A sample collected from here was crushed and elutriated in the Geological Survey Laboratory, yielding 17·8 per cent. (by weight) of white clay, and 82·2 per cent. of good clean quartz-sand. The clay is plastic and retains its colour when burnt at 1400°C., without showing any tendency to fuse. It becomes quite hard but contracts by about 12 per cent. of its volume. Though I had no opportunity of making any reliable estimate of the quantity available, I should think the deposit will pay to work for its kaolin and quartz sand. The location is however not very favourable, since it is over 20 miles distant from the railway, and separated from it by a strip of rather hilly country.

Adjoining the carbon-phyllite band at Kundrugutu (22° 26′: 84° 56′) there is a band of nearly white shale which extends for about 300 yards along the strike, on each side of the Deo river. Its exposed width is variable from place to place but an average width of 50 yards may be taken. In the same stratigraphical position, a thin band of similar material was found further east, and also near Kardega (22° 25′: 84° 47′) and Baraibora (22° 23′: 84° 49′). A specimen from the Kundrugutu exposure proved to be a fairly good kaolin, and the deposit is potentially useful. Some of it may be useful as a 'filler,' after washing and separating the gritty admixture.

Black carbonaceous phyllite.

The two carbonaceous phyllite horizons in the anticlinorium, as well as the bands of the same rock occurring in the south-eastern part of the area in the Iron-ore series locally, contain soft black shaly rocks which can be used for making black paints. Such rocks have been used for this purpose in recent years. Near Hetpos, Amghat,

Kumarmunda, Talsara, Kacharu, Karimati, Kulagoja and other places, very large quantities of this rock are available, and should this material be found suitable on trial, the quantities obtainable may be considered inexhaustible.

Barytes[1].

There are two occurrences of barytes in this area, one near Kolpotka (22° 21′ 30″ : 85° 5′ 30″) in Singhbhum and the other near Khatangtola, about a mile to the north-west of the former, and within the borders of Gangpur State.

The Kolpotka occurrence[2] is found about half a mile to the south-west of that village on either side of a small valley. The barytes (M. 966) occurs in anastomosing veins in mica-schist. The southern zone is about 500 yards by 150 yards in extent. The veins generally follow the foliation planes of the mica-schists which here dip towards S. 40°E. at an angle of about 70°. Part of the country rock is also replaced by the barytes and by accompanying limonite. At the time of my visit late in 1927, an open-cast quarry in this deposit was being worked by Mr. S. S. Guzdar of Calcutta. The vein material was broken by hand to lumps of one to two inches in size. Only the best white lumps were selected for export to Calcutta, the stained portions being rejected at the quarry. The exportable quality formed only about five to seven per cent. of the veinstuff. At the time of my visit, the labour force consisted of 15 persons including women, and the daily output was between two and two and a half tons, which was railed from the Jaraikela station of the B. N. Railway. The quarrying operations apparently ceased in the following year.

The northern zone, which was located about 300 yards north of the above, was marked by three or four small pits showing poor mineralisation. I gathered that there was no production from this zone.

The second occurrence[3] is about half a mile east of Khatangtola (22° 22′ : 85° 4′). In April, 1931, when I happened to visit the place, the deposit was just being opened up by Mr. W. S. Young of Kalunga. There is a small rise in the ground extending in a north-

[1] *See* also, A. L. Coulson, Barytes in the Ceded Districts of Madras, with notes on its occurrence in other parts of India. *Mem. Geol. Surv. Ind.*, LXIV, Pt. 1, pp. 92, 93, (1933).
[2] *Rec. Geol. Surv. Ind.*, LXII, p. 31, (1928).
[3] *Rec. Geol. Surv. Ind.*, LXVII, p. 24, (1933).

west—south-east direction for about a hundred yards. A vein of barytes, about three feet thick, was exposed in a shallow pit under an overburden of barely two feet. The vein consisted of good barytes (N. 488) with a small amount of quartz, the limonite staining being less conspicuous than at Kolpotka. About 50 per cent. of the barytes recovered was of the best exportable quality. This seems to have been worked only for a few months in 1931 and 1932. Mr. Young informs me that the total quantity exported from this quarry was 445 tons of uniformly excellent grade. At the time of stopping work, in July, 1932, the quarry was 120 feet long, 50 feet wide, and about 18 feet deep. It is expected to be re-opened soon.

The specimen of barytes (N. 655) said to have come from a locality two miles to the east of Garpos station in Bamra State,[1] has since been ascertained to have been obtained from Khatangtola by a local man who expected to benefit by imparting the false information to Mr. Young. On investigation, Mr. Young found that the alleged find was a hoax.

Red ochre. (Red Iron Oxide).

In the chapter describing the Gondwanas, a band consisting of vitrain and ochre (13/188) has been mentioned as occurring in the coal exposure in the Baisundar *nala* above its confluence with the Jhajia *nala* north of Gopalpur. The ochre band has been followed from the above exposure along the northern bank of the Baisundar to a point south of Tiklipara, *i.e.*, over a length of nearly a mile and a half. The thickness of this band varies between 9 and 12 inches. When exposed at the surface the ochre is red-brown to orange-red in colour, but freshly broken lumps are bright cherry-red, soft and powdery (N. 486 and 487). The apparent density of the material, determined on pieces covered with a thin layer of paraffin wax, was 1·82 to 1·90 (about 118 lbs. per cubic foot or 19 cubic feet to the ton). Assuming, for the workable portion of the deposit, a length of 1 mile, a width of 150 ft., and an effective average thickness of $\frac{1}{3}$ ft., which are believed to be quite conservative, the available quantity works out at 13,895 tons (or say 14,000 tons). The quality of the pigment is good, as most of it passes 300 mesh and has a colour corresponding closely to 'maho-

[1] A. L. Coulson, *loc. cit.*, p. 92.

gany red' in Ridgway's[1] classification. A sample of the 'ochre' was analysed with the result given below:—

TABLE 26. -*Analyses of 'red oxide' pigments.*

	A	B	C
	Per cent.	Per cent.	Per cent.
SiO_2	1·51	18·7	5·3
Al_2O_3	1·52	2·8	1·7
Fe_2O_3	87·72	72·5	91·0
MgO	trace.	2·5	*Nil.*
CaO	trace.	0·7	trace.
Loss on ignition	5·46	1·0	1·3
Moisture	3·90	1·4	0·5
TOTAL	100·14	99·85	99·8

A. Bright red oxide from Gangpur State.
B. Bright red oxide from the Persian Gulf region.
C. Purple oxide (Olphert's oxide) from Katni, Central Provinces.

The above analysis (A) shows that it is a high-grade hydrated oxide of iron. Though the two constituents, vitrain and ochre, occur mixed to some extent, some portions show the ochre forming the major portion of the band. It is thought that the two constituents are amenable to easy separation, since the ochre, being heavy (true density over 3·6) and powdery and easily disintegrating in water, can be separated to a large extent from the lighter (density 1·35) and coarser carbonaceous matter by a suitably devised process of washing and settling.

The Himgir sandstone, which occupies the greater part of the Himgir *Zamindari*, contains ochery material in the groundmass, and also as pockets and thin seams. In the course of mapping, I observed such material in and around the town of Himgir. A specimen (P. R. 6664) received by this Department for determination from the hill near Kund (22° 1′ : 83° 42′) was a dark, compact,

[1] R. Ridgway, Colour standards and colour nomenclature. New Yokr (1910).

chocolate coloured, rather gritty material, which improved in quality on grinding and washing. It is therefore likely that careful examination of these sandstones will reveal small workable deposits of good ochre.

Soapstone.

There are only two insignificant occurrences of talc-schists in the area, one near Katepur and the other near Jarmal. At the latter village a small exposure of soapstone was found on the banks of a small stream draining into the Sapai *nadi*. A well sunk in the village met a thickness of some four to five feet at a depth of 20 feet. As the neighbourhood is covered by thick soil, the extent and thickness of the stone could not be ascertained. It is however thought that the deposit is not of much importance.

The Katepur occurrence is quite small and consists of a rather fibrous antigorite variety. Its surface extent is only about 40×8 square feet.

Ironstone (Limonite).

The several patches of laterite occurring in the area contain lumps of impure ironstone. Such are particularly common on the limestone and epidiorite exposures. Though of no economic importance at present, they seem to have been used as sources of iron-ore formerly, when the local needs of iron were met by primitive smelting in all parts of the country. In many places I noticed the presence of ancient slags, which bear evidence of local smelting operations. The industry became extinct during the latter half of the last century, when iron from Europe became available to the people.

Quartz and quartz-sand.

The whole area is full of quartz veins of different dimensions. A few of these, large enough to be mapped, have been shown on the accompanying geological map. Those occurring near Bamra, Damdapara near Birmitrapur, Kichinda, Haldipani, Malsara and Targa may be mentioned as practically pure masses. They may be useful as a source of quartz for ceramic and other purposes. Some of the occurrences are however associated with tourmaline.

Vein-quartz.

The quartzites forming several of the hills are usually impure, micaceous and ferruginous. Particular bands or portions are sufficiently pure to serve as sources of silica. For example, a part of the hill about a mile to the south-west of Jara (22° 1′ : 84° 39′) is exceptionally pure quartzite and contains only occasional grains of kyanite as an impurity. Quantities running into several thousand tons should be easily available here.

Quartzite.

Some beds of the Barakar sandstones near Amatpani contain excellent high grade quartz-sand in a matrix of kaolin. The sample from which kaolin was separated and tested (*see* p. 174 under kaolin) showed 82 per cent. of quartz-sand which contained only 0·2 per cent., by weight, of other minerals. This deposit should prove to be a source of good glass-sand and kaolin.

Quartz-sand.

Felspar.

Pegmatite veins containing very coarse masses of potash felspar (orthoclase and microcline) are very abundant in the regions bordering on the granite exposures and in the extensively granitised area around Darlipali, Sargipali, Ghantbur, *etc.* These should prove useful for supplying the needs of a ceramic industry if one should be started near about this region.

Muscovite.

Associated with the pegmatite veins, there are small 'books' of muscovite mica in several places. Near Ghoriajor, Tangarmunda (between Bamra and Garpos), Potatangar (22° 0′ : 84° 33′) in Bonai State and a few other places, 'books' up to three inches in diameter have been found. But as the mineral is full of flaws and of small dimensions, it need not be considered to be of economic importance.

Building stones.

Granite.

In the main mass in Ranchi and in its offshoot around Talsara, the granite is a medium grained and equigranular rock of white to light pink colour, suitable for dressing as building stone. The bosses around Ekma and near Itma are also suitable where not cut

up too much by coarse pegmatitic veins. The exposures of pink granite-gneiss near Jara will also make good building stones.

Quartz-schist.

Most of the areas marked as quartzites and quartz-schists on the map contain enormous masses of micaceous quartz-schists, which can easily be split up into slabs along the planes of foliation. Such material occurs in the hills south and east of Lifripara, and also in the hills two miles north-west of Ujalpur. A small quarry was operated in the latter by the Gangpur State for paving stones to be used in houses at Sundargarh. Some of the slabs quarried here measured five feet by three feet and one to three inches in thickness, the thickness of each slab being uniform. In 1931 I noticed several cart loads being sent to Ujalpur and Sundargarh.

The coarser and less uniform grained rocks are also used locally for building the piers of the temporary culverts and bridges and as protective embankments alongside the stream banks. Such rocks can be had in abundance in practically all the hills composed of quartz-schists.

Limestone.

The impure bands of limestone from the marble beds have also been used as building stones, near the different quarries. At Birmitrapur, some houses, and especially the huts of the labourers, have been constructed of limestone.

Slate.

The carbon phyllite band locally passes into fissile slate in some places (*e.g.* near Hetpos, Talsara, Kumarmunda, *etc.*).

Thin slabs, up to six feet long and less than an inch in thickness, have been cleaved out of these and used as fencing and paving slabs in some of the villages. Much thinner slabs can be easily split from some of the exposures, and material suitable for school-slates has also been occasionally observed. Large quantities of slate suitable for use as paving stone are certainly available, though finer qualities are probably of very restricted distribution.

Laterite.

There are patches of lateritised rock in many places in Gangpur State. These however are generally superficial and do not extend

to any depth. No attempt seems to have been made to use this material for building purposes.

Road metal.

Though granite, gneiss and epidiorite are available in several parts of the area under consideration, they have not been used in road making. The roads consist of an earthen embankment which is surfaced with '*moram*' or lateritic gravel. When this material is good it consolidates into a sound, fairly hard and smooth surface, the limonitic constituent acting as the binder. The less important roads are nothing more than mere earth embankments which are easily cut up by any good shower of rain.

Soils.

The soils of the area can generally be classified under 'red soils' derived from the mica-schists and granitic gneiss. The mica-schists are excellent soil-formers and support a large population on agriculture. The low plains and stream valleys are cultivated, rice being the chief crop. The granite areas are generally rocky. The epidiorite bands frequently give rise to a rich red-brown soil, which supports 'dry' crops.

The area under agriculture has steadily increased during the past century at the expense of the magnificent forests which once covered the greater part of the region. Owing to the absence of irrigation works, only a single crop could be harvested per year except in some of the stream valleys. The encroachment on forest areas has been greatly restricted during the last decade or two after the adoption of modern methods of forest conservation.

NOTE.—A little additional information on the minerals of Gangpur will be found in the discussion of my paper on 'the economic minerals of Gangpur State' (*Trans. Min. Geol. Inst. Ind.*, XXX, Pt. 2, 92-101, (1936). I have also heard that some books of mica, up to two feet in diameter, were found in pegmatite near Sarapgarh.—M. S. K.

SUBJECT INDEX.

GEOGRAPHIC INDEX.

MGIPC—M—VIII-4-4—10-5-37—725.

P L Dutt Photo

FIG 1 SPECIMENS OF HIGHLY FOLDED, BANDED, CARBONACEOUS QUARTZITE, FROM TANGRABAHAL

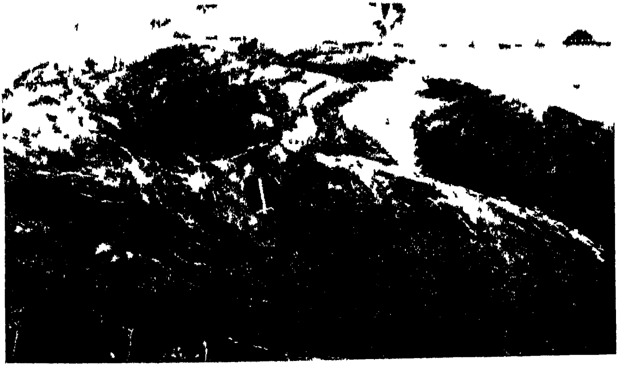

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FIG 2 EXPOSURE OF FOLDED MARBLE, NEAR PURKAPALI

FIG. 1. VIEW, LOOKING NORTH, OF THE SANKH RIVER FLOWING THROUGH GRANITE COUNTRY NEAR MARAROMA.

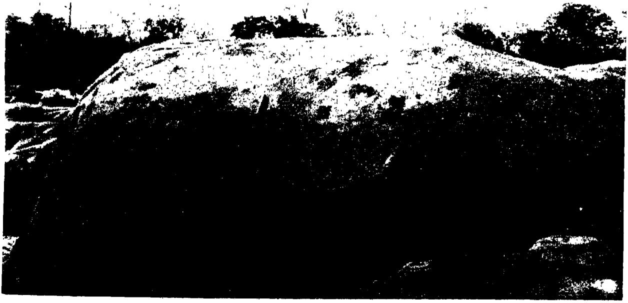

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FIG. 2. GRANITE BOULDER SHOWING DENDRITIC SEGREGATION PATCHES OF TOURMALINE, NEAR MARAROMA.

FIG 1 SILLS OF PEGMATOID GRANITE INTRUSIVE INTO MICA SCHISTS, AT THE JUNCTION OF THE IB AND THE SAPAI NEAR BHASMA

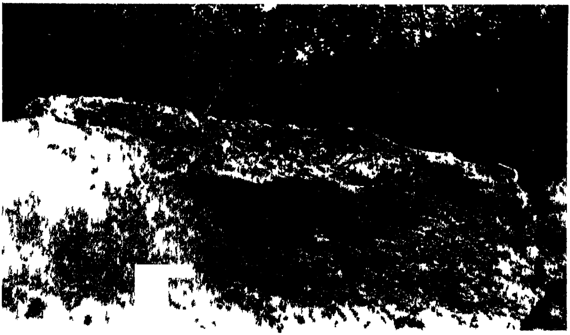

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FIG 2 MICA-SCHIST CAUGHT UP AND PARTIALLY ASSIMILATED BY GRANITE NEAR GHANTBUR

Memoirs, Vol. 71, Pl. 5.

FIG. 1. FINELY FOLIATED MICA-SCHISTS IN THE STREAM ONE MILE NORTH OF NUAPALI.

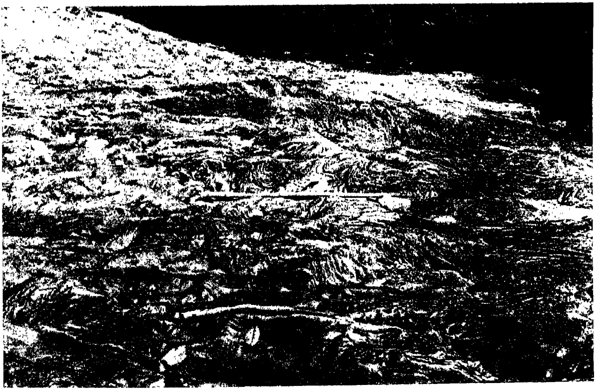

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FIG. 2. FINELY FOLIATED MICA-SCHISTS IN THE STREAM ONE MILE NORTH OF NUAPALI. (Locality near that of fig. 1).

FIG. 1. SLATY PHYLLITES EXPOSED IN A STREAM NEAR BINJO.

M. S. Krishnan, Photos. *G. S. I., Calcutta.*

FIG. 2. ROUGHLY JOINTED QUARTZITES IN THE KUKRA *NALA* ONE MILE NORTH-WEST OF TILDEGA.

FIG. 1. CHARACTERISTIC WEATHERING OF BARAKAR SANDSTONE, NEAR AMATPANI.

M. S. Krishnan, Photos. *G. S. I., Calcutta.*

FIG. 2. EXPOSURE OF COAL ON THE LEFT BANK OF THE BAISUNDAR RIVER, NORTH OF GOPALPUR.

FIG 1. VIEW OF THE MANGANESE QUARRY (BARAGARHA) AT GHORIAJOR

M. S Krishnan, Photo *G S I, Calcutta*

FIG. 2. FOLDED GONDITE AND QUARTZITE IN A SMALL QUARRY ADJOINING MOHALGARHA NEAR MANOMUNDA

FIG. 1. GENERAL VIEW OF THE MIDDLE HILL AT BIRMITRAPUR.

M. S. Krishnan, Photos. *G. S. I., Calcutta.*

FIG. 2. A VIEW, FROM THE EAST, OF THE LARGE BATTERY OF KILNS, BIRMITRAPUR.

FIG 1

R F Alexander, Photos

G. S. I., Calcutta.

FIG 2

FIGS. 1 & 2. LIMESTONE QUARRIES AT BIRMITRAPUR, SHOWING THE METHOD OF WORKING

Memoirs, Vol. 71, Pl. 11.

R. F. Alexander, Photo.

FIG. 1.

M. S. Krishnan, Photo. *G. S. I., Calcutta.*

FIG. 2.

FIGS. 1 & 2. LIMESTONE QUARRIES AT KAPLAS NEAR BIRMITRAPUR.

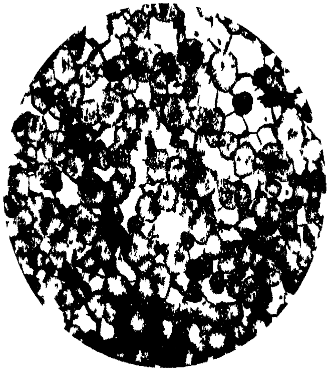

FIG 1 TYPICAL GONDITE (QUARTZ SPESSARTITE ROCK) FROM GHORIAJOR (× 36)

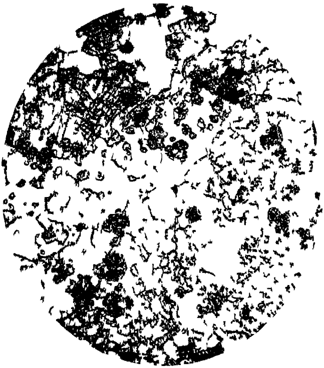

FIG 2 QUARTZ RHODOCHROSITE RHODONITE ROCK, FROM GHORIAJOR (× 24)

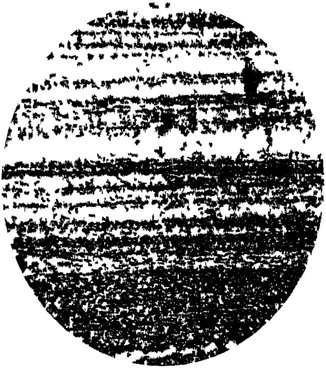

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FIG 3 BLANFORDITE-RHODONITE QUARTZ ROCK WITH A LITTLE FELSPAR AND BARYTES FROM A QUARRY NEAR MANOMUNDA (× 24)

FIG 4 BANDED CARBONACEOUS QUARTZITE FROM HETPOS (× 36)

FIG 1 CARBONACEOUS PHYLLITE WITH CHLORITOID NEAR BANSJOR SOUTH OF HATHIBARI (X 24)

FIG 2 CARBONACEOUS SCHIST WITH ABUNDANT TOURMALINE CONTAINING CARBONACEOUS INCLUSIONS, FROM THE HILL 1159 SOUTH OF KHATKURBAHAL (X 36)

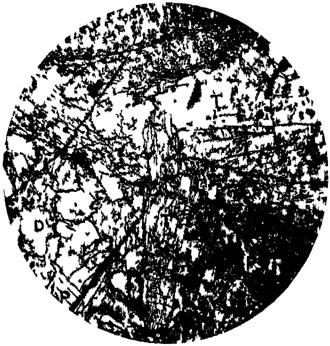

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FIG 3 TREMOLITE DOLOMITE SCHIST WITH PHLOGOPITE, PURKAPALI (X 24)
T—Tremolite, D—Dolomite, P—Phlogopite

FIG 4 CRYSTALLINE LIMESTONE WITH ALBITE, RAIPURA (BIRMITRAPUR) (X 16)
A—Albite

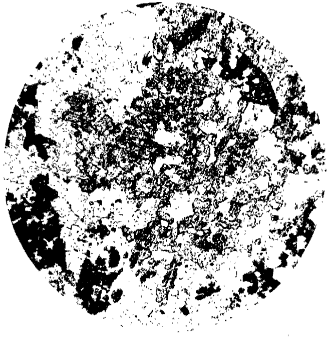

FIG. 1. CALC-GNEISS (DIOPSIDE-ACTINOLITE-QUARTZ-FELSPAR ROCK) FROM AN EXPOSURE IN THE SAPAI NEAR BHASMA. (× 24).

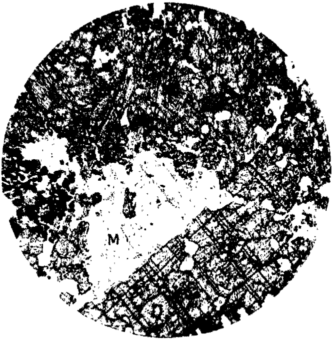

FIG. 2. CALC-GNEISS (DIOPSIDE-ACTINOLITE-MICROCLINE-QUARTZ ROCK), BIRTOLA. (× 24).
D—Diopside; A—Actinolite; M—Microcline.

P. L. Dutt, Photomicros.

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FIG. 3. SAME AS FIG. 2, UNDER CROSSED NICOLS TO SHOW MICROCLINE. (× 24).
M—Microcline.

FIG. 4. CALC-GNEISS (HYBRID BETWEEN CALCAREOUS ROCK AND GRANITE) WITH BLADED AND SKELETAL CRYSTALS OF ACTINOLITE, ZOISITE AND QUARTZ, NEAR HATHIBANDHA. (× 24).

FIG. 1. GARNET-AMPHIBOLE-HORNFELS FROM A RAILWAY CUTTING NEAR THERALIBAHAL. (× 24). G—Garnet; A—Amphibole.

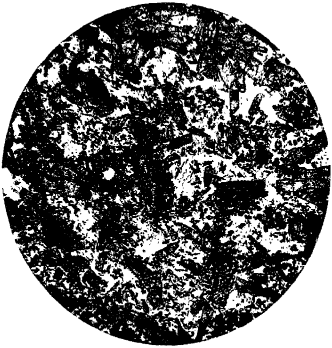

FIG. 2. GARNET-PYROXENE-AMPHIBOLE-HORNFELS FROM NEAR THERALI-BAHAL. (× 24).

P. L. Dutt, Photomicros.

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FIG. 3. BRECCIATED QUARTZITE (FAULT-BRECCIA), FROM THE RIDGE WEST OF KATRA. (× 16). Note the comb-structure in the Secondary Veins.

FIG. 4. PLAGIOCLASE-AMPHIBOLITE FROM THE BASIC SILL ONE MILE SOUTH OF KUKURA. (× 24).

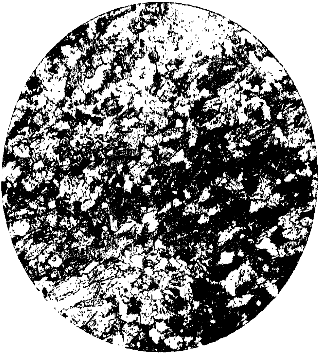
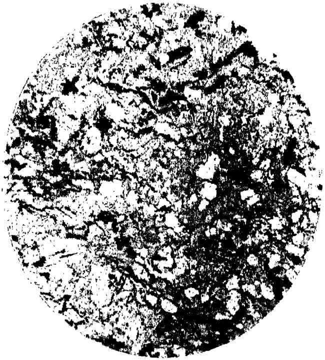


FIG. 1. PLAGIOCLASE-AMPHIBOLITE WITH HORNBLENDE, PLAGIOCLASE, ZOISITE AND SPHENE, FROM AN EXPOSURE IN THE STREAM NEAR KURAI. (× 24).

FIG. 2. SERPENTINISED BASIC ROCK FROM NEAR CHANDIPOSI. (× 24).



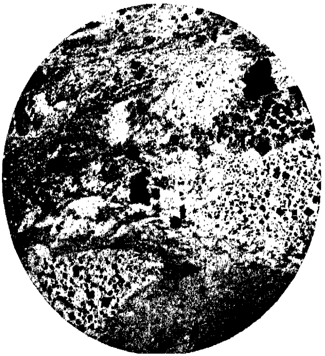


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FIG. 3. EPIDIORITE, DAMKURA. (× 24).

FIG. 4. CHLORITIC CONGLOMERATE SHOWING MARTITE IN THE JASPER PEBBLES AND DOLOMITE IN THE CHLORITIC GROUNDMASS, RIGHT BANK OF THE STREAM NEAR THIATANGAR. (× 24).

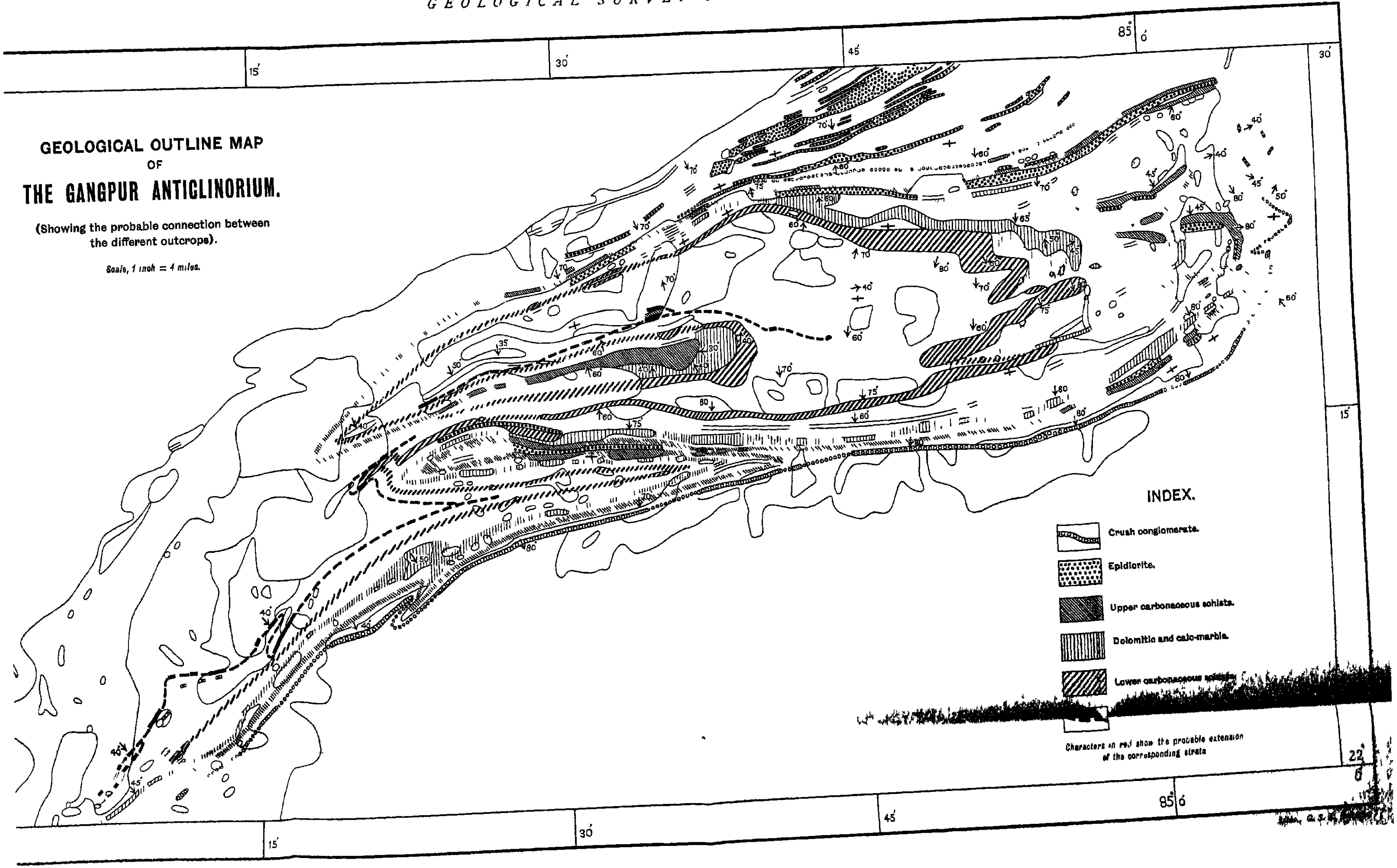
G. S. I., Calcutta.

P. L. Dutt, Photomicros.

FIG. 1. GARNET-STAUROLITE-BIOTITE-SCHIST FROM POTOB. (× 24). G—Garnet; S—Staurolite.

FIG. 2. GARNETIFEROUS MICA-SCHIST SHOWING GARNET AND BIOTITE PORPHYROBLASTS ASKEW TO FOLIATION FROM NEAR GOGHIA, WEST OF SATRA. (× 16). G—Garnet; B—Biotite.

FIG. 3. ROCK SHOWING SIMILAR FEATURES FROM NEAR BANSJOR, SOUTH OF HATHIBARI. (× 16). G—Garnet.


GEOLOGICAL OUTLINE MAP
OF
THE GANGPUR ANTICLINORIUM.
(Showing the probable connection between the different outcrops).
Scale, 1 inch = 4 miles.
INDEX.
Crush conglomerate.
Epidiorite.
Upper carbonaceous schists.
Dolomitic and calc-marble.
Lower carbonaceous schists.
Characters in red show the probable extension of the corresponding strata
85° 0'
15'
30'
45'
22°

MEMOIRS

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VOLUME 71.

THE GEOLOGY OF GANGPUR STATE, EASTERN STATES. BY M. S. KRISHNAN, M.A., PH. D. (LOND.), A.R.C.S., D.I.C., *Geologist, Geological Survey of India.* (With Plates 1 TO 19.)

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PUBLISHED BY THE MANAGER OF PUBLICATIONS, DELHI.